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REFERENCE

Lane, B. H., 1935, Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C. 35c.)

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NEPHELINE-ALKALI FELDSPAR PARAGENESES

C. E. TILLEY

ABSTRACT. The composition of the nepheline phase in nepheline-alkali feldspar parageneses is considered in the light of the experimental evidence of changing equilibrium relations among alkali feldspar phases with temperature.

In alkali feldspar gneisses with nepheline (metamorphic or metasomatic) and nepheline syenites carrying albite ± microcline, the composition of the nepheline phase is normally represented in a convergence field (in the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2) adjacent to the Buerger normal nepheline composition but covering that originally suggested by Morozewicz for rock-forming nepheline; in chemically equivalent high temperature assemblages carrying the diagnostic anorthoclase-sanidine series of feldspars, the nepheline phase is not restricted to the convergence field but varies with the chemical environment.

The contrasted feldspathoid-feldspar associations in the heteromorphic pair—phonolite and nepheline gneiss—are explicable in terms of equilibrium reaction processes with changing temperature of the type for a sodic phonolite metamorphism,

(soda-rich NaK nepheline) + (anorthoclase) → (NaK nepheline) + (albite + microcline)
(phonolite) (nepheline gneiss)

the bulk composition of the feldspar phases in the nepheline gneiss becoming relatively more sodic, the nepheline more potassic.

New analyses of nephelines in contrasted parageneses are presented.

The conspicuous advances which have followed recent experimental investigations on phase equilibria among alkali feldspar minerals give good ground for belief that the heteromorphy displayed in the series will provide an index of the physical conditions under which rock assemblages containing them have finally consolidated or recrystallized. Suggestive applications of these results to the interpretation of rocks of syenitic and granitic chemistry have already been made by Tuttle (1952a) and Bowen and Tuttle (1950, 1952).

The knowledge thus gained of alkali feldspar associations and its interpretation for geologic thermometry may well be of service in considering like problems of another great group of rocks, the nepheline syenites and their chemical equivalents, of which soda-potash feldspars and a nepheline solid solution are essential constituents.

The problem of the composition range of nepheline has already been the subject of study by a number of authors, including Morozewicz (1928), Bannister and Hey (1931), Bowen and Ellestad (1936), Buerger et al. (1947), Miyashiro (1951), and Tilley (1952). Some additional data have more recently been supplied (Tilley, 1953a, 1953b).

While it is clear both from synthetic studies and some natural parageneses that the composition of nepheline is conditioned by the chemical environment, there are other indications as pointed out by Miyashiro that physical control plays a prominent part in restricting the composition range. Buerger and his collaborators (1947; Washken and Buerger, 1950) from

crystal structure considerations derived a formula for normal nepheline with a Na:K ratio of 3:1 ($Na_3KAl_4Si_4O_{16}$, weight percent $Ne_{73}Kp_{27}$), and they indicated that in the tridymite-like framework of the silicate the alkalis are present in two unequivalent forms, larger holes in the framework accommodating K atoms and smaller holes Na atoms.

If this indeed be the ideal formula of nepheline, the conditions of its realization would appear characteristically to be those of low temperatures, and the real evidence of wide departure from this composition related in part to crystallization at elevated temperatures which permit freer occupation of alkali sites in the structure.

It is here that the new data on the alkali feldspars providing an index in geologic thermometry may be expected to be useful in assessing the composition problem of nepheline.

From a survey of published analyses of natural nephelines it was already apparent that the extremes of composition in the series at the soda end were provided in the analyses of the nepheline from the grennaite of Norra Kärr and on the potassic side by the nepheline of a nephelinite from Kenya ($Ne_{91.7}Kp_{8.3}$ and $Ne_{60.6}$ $Kp_{39.4}$ respectively) (Tilley, 1952, table 1, p. 169).

More recent data modify these limits. In the first place, Sahama (1952) has recorded a more potassic nepheline ($Ne_{54.7}$ $Kp_{45.3}$) from a potash ankaratrite from the Belgian Congo, and reasons have been given for questioning the Norra Kärr analysis, a related grennaite rock yielding a nepheline of composition much less sodic, the reported development of anorthoclase in these grennaite assemblages being also questioned (Tilley, 1953b).

The most sodic nephelines to date are found at Vesuvius, associated with a limestone xenolith (Bannister and Hey, 1931, table 1, p. 572), at Coimbatore, Madras (Subramaniam, 1949) in a nepheline pegmatite, and

TABLE 1

	1	2	1a		2a		
SiO_2	52.97	44.65	Norm of 1		Metal atoms to 32 Oxygens in 2		
Al_2O_3	18.54	32.03					
Fe_2O_3	3.91	0.59	Or	22.80	Si	8.62	15.90
FeO	3.02		Ab	35.37	Al	7.28	
MgO	1.94	Nil	Ne	16.90	Ca	0.15	Σ R 7.20
CaO	3.39	0.71	Hl	0.58	Na	6.45	
Na_2O	8.21	17.25	An	3.61	K	0.45	
K_2O	3.90	3.66	Di	8.55			
H_2O-	0.91	0.21	Ol	1.42	$Ne_{82.0}Kp_{12.8}Qz_{5.2}$		
H_2O+	1.59	0.96	Il	1.82	($Ne_{86.5}Kp_{13.5}$)		
TiO	0.93	Nil	Mt	5.57			
P_2O_5	0.40		Ap	1.01			
MnO	0.17		Rest	2.59			
Rest	0.44						
	100.32			100.22			
Less O	0.08		$Ne_{48.0}Kp_{17.5}Qz_{34.7}$				
= Cl		100.06			ω 1.535,		ε 1.531
	100.24						

1 Phonolite with phenocrysts of nepheline and anorthoclase, pebble from older "phonolitic conglomerate," near Abbot's Hill, Dunedin, New Zealand. Anal. F. T. Seelye. Rest includes Cl 0.35, BaO 0.06, SrO 0.03, CO_2 trace.

2 Nepheline, phenocrysts in phonolite (no. 1). Anal. J. H. Scoon.

at Monte Ferru, Sardinia, (Washington and Merwin, 1915) in a phonolitic trachyte (Tilley, 1952, fig. 1, p. 168).

In a search for further examples of the more sodic nephelines, and a study of their environment, I had occasion to inquire of Professor Benson for possible examples among the suite of rocks from his Dunedin alkali province.

In response he very kindly forwarded to me a very beautiful aegirine-augite phonolite from Dunedin rich in fresh nepheline phenocrysts along with porphyritic anorthoclase, the rock itself having already been analyzed by Mr. F. T. Seelye. The nepheline of this rock has been separated and analyzed by Mr. J. H. Scoon with the results set down in table 1, no. 2.

This nepheline proves to be among the most sodic on record, and I am much indebted to Professor Benson for permission to make use of this analysis and especially of the analysis of the phonolite itself (table 1, no. 1).

The associated anorthoclase which occasionally contains small cores of a plagioclase phase, and is itself zoned, has the following properties: α 1.523, γ 1.531, extinction on 001 = 7°. It is therefore probably close in composition to the Grande Caldeira, Azores anorthoclase studied by Tuttle (1952b, p. 555).

The composition of the phonolite and its contained nepheline is plotted in the usual diagram (fig. 1), the tie line of composition being shown as D—D'. It has the trend of other volcanic phonolites containing members of the high temperature sanidine-anorthoclase series.

Other soda-rich nephelines occur in a more deepseated environment in Burma as constituent minerals of the nepheline syenite suite of the Mogok district.

The first recorded occurrence of nepheline in Burma is contained in reports by Adams (1926, p. 20-21) and Adams and Graham (1926, p. 113-136). They described from Sinkwa, near Mogok, under the name urtite, a rock occurring in bands two to three feet wide and appearing like dikes in the marbles of the Mogok series.

It was recorded as composed essentially of greenish-yellow elaeolite and black aegirine-augite with accessory sphene, calcite, microcline, apatite, and iron ore.

Subsequently Banerji (1932) showed that there were further developments of feldspathoid rocks in the Mogok district near the Lishaw village of Chaunggyi (jacupirangite, ijolite and a nepheline corundum syenite), again associated with limestone.

The most interesting of the nepheline parageneses recorded was that related to a feldspar (albite) rock intruded into coarse-grained limestone at Sontabe Taung, N.E. of Mogok, the nepheline appearing at the contact along with diopside, calcite, and feldspar (Banerji, 1932, p. 22, 95).

On these interesting nepheline developments no further work appears to have been published.

Apart from their limestone environment these nepheline parageneses are of interest inasmuch as the nepheline mineral is in some cases at least a soda-rich type comparable in composition with those met with in the sodic phonolites.

TABLE 2

	1	2	3	Metals to O = 32 (nephelines 1 and 2) 1a			2a		
SiO_2	43.42	43.24	65.76	Si	8.31	15.96	Si	8.35	15.97
Al_2O_3	33.92	33.56	20.23	Al	7.65		Al	7.62	
Fe_2O_3	0.14	0.47	0.18						
MnO	Nil	Nil	Nil	Ca	0.27	Σ R 7.79	Ca	0.13	Σ R 7.74
MgO	0.08	0.05	0.10	Na	6.31		Na	6.32	
CaO	1.37	0.77	1.19	K	0.94		K	1.16	
Na_2O	17.05	16.88	8.44						
K_2O	3.85	4.71	3.29						
H_2O	0.11	0.07	± 0.45	Ne	83.3		Ne	80.4	
CO_2	—	0.11*		Kp	13.8		Kp	16.4	
TiO_2	Nil	Nil	0.08	Qz	2.9		Qz	3.2	
BaO	—	—	0.63						
	99.94	99.86	100.35	ω 1.536, ε 1.532			ω 1.538, ε 1.534		

* Present as calcite.

1 Nepheline, from "jacupirangite" N.W. of Lishaw village of Chaunggyi, Mogok district, Burma.

2 Nepheline from ijolitic nepheline syenite, Sinkwa, Mogok district, Burma.

3 Soda-rich orthoclase cryptoperthite ($Or_{19.8}$ $ab_{72.7}$ $An_{6.0}$ $Ce_{1.5}$) associated with nepheline (no. 2) in ijolitic nepheline syenite.

So much can be gathered from inspection of examples available for study at Cambridge and received some years ago through the courtesy of the Geological Survey of India.

The jacupirangite of Chaunggyi mentioned above is a variable rock rich in gray-green clinopyroxene with some pleochroic brown hornblende and nepheline. Accessories include biotite, apatite, calcite, and a little oligoclase. From a nepheline-rich part of the rock the nepheline was extracted and gave on analysis (table 2, no. 1) the composition $Ne_{77.8}Kp_{12.9}An_{6.7}Qz_{2.6}$.

Of greater interest in the present connection is the ijolitic nepheline syenite of Sinkwa, a specimen of which answers to the megascopic description given by Adams and Graham (1926).

It is a medium-grained rock with a modal composition as follows: nepheline 40.8, clinopyroxene 39.5, alkali feldspar 9.5, sphene 4.2, calcite, magnetite, and apatite 6.0.

The nepheline shows the greenish-yellow color described by Adams and the clinopyroxene, strongly pleochroic Z yellowish-green, X and Y shades of olive green, corresponds to a variety of aegirine-augite.

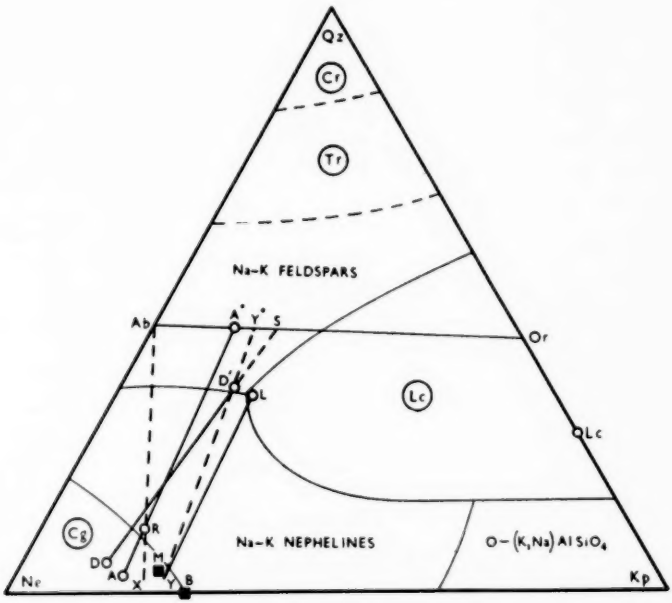

Fig. 1. Plot of analyses of nephelines (D,A,Y) and feldspar (A''), and of the salic normative composition of host rocks (D',L) in the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2.

D–D'—phonolite, Dunedin, New Zealand (table 1); A–A''—ijolitic nepheline syenite, Burma (table 2, no. 2); A''—composition of the soda-potash feldspar (table 2, no. 3). R—modal felsic composition of the Burma ijolitic nepheline syenite. L–Y tie line of nepheline syenite, Blue Mt., Ontario (Tilley, 1952, p. 173). M and B nepheline formulae of Morozewicz and Buerger respectively. For the interpretation of the lines XRAb and YD'Y'' see text.

Only one feldspar type is present, finely perthitic and showing in patches a very fine grid structure reminiscent of microcline. The optical properties, however, correspond to a sodic member of the orthoclase cryptoperthite series, behaving normally as a monoclinic mineral Z = b and extinction on 010, XΛ 001 = 14°, α 1.528, β 1.533, γ 1.537, 2V = 78°.

TABLE 3

Nepheline-Feldspar Parageneses

Mariupolite Series, Azov, Russia (Morozewicz, 1930)					
1	$Ne_{74\cdot1}$	$Kp_{21\cdot8}$	$Qz_{4\cdot1}$		Feldspar associations Albite ± microcline
2	$Ne_{74\cdot7}$	$Kp_{20\cdot9}$	$Qz_{4\cdot4}$		
3	$Ne_{75\cdot3}$	$Kp_{20\cdot0}$	$Qz_{4\cdot7}$		
4	$Ne_{76\cdot0}$	$Kp_{18\cdot8}$	$Qz_{5\cdot2}$		
5	$Ne_{76\cdot1}$	$Kp_{19\cdot2}$	$Qz_{4\cdot7}$		
Average 1-5	$Ne_{75\cdot3}$	$Kp_{20\cdot1}$	$Qz_{4\cdot6}$		
Haliburton-Bancroft area, and French River, Ontario					
6	$Ne_{71\cdot9}$	$Kp_{22\cdot8}$	$Qz_{5\cdot3}$	(York River)	feldspar associations albite + microcline *unpublished analysis
7	$Ne_{72\cdot6}$	$Kp_{20\cdot6}$	$Qz_{6\cdot8}$	(French River)	
8	$Ne_{73\cdot5}$	$Kp_{21\cdot6}$	$Qz_{4\cdot9}$	(Blue Mt.)	
9	$Ne_{76\cdot1}$	$Kp_{19\cdot2}$	$Qz_{4\cdot7}$	(Gooderham)	
10	$Ne_{78\cdot2}$	$Kp_{16\cdot2}$	$Qz_{3\cdot6}$	(York River)	
11	$Ne_{75\cdot1}$	$Kp_{22\cdot2}$	$Qz_{2\cdot7}$	(Blue Mt.)	
12*	$Ne_{76\cdot7}$	$Kp_{20\cdot8}$	$Qz_{2\cdot5}$	(Craigmont)	
13*	$Ne_{76\cdot8}$	$Kp_{20\cdot1}$	$Qz_{3\cdot1}$	(Bancroft)	
14*	$Ne_{77\cdot6}$	$Kp_{20\cdot0}$	$Qz_{2\cdot4}$	(York River)	
Average 6-14	$Ne_{75\cdot4}$	$Kp_{20\cdot6}$	$Qz_{4\cdot0}$		
15	$Ne_{73\cdot7}$	$Kp_{24\cdot8}$	$Qz_{1\cdot5}$	(Norra Kärr)	feldspar associations albite + microcline *unpublished analysis
16	$Ne_{74\cdot4}$	$Kp_{24\cdot1}$	$Qz_{1\cdot5}$	(Vaal River)	
17*	$Ne_{76\cdot5}$	$Kp_{20\cdot5}$	$Qz_{3\cdot0}$	(Nyasaland)	
Soda-rich nephelines					
18	$Ne_{76\cdot5}$	$Kp_{13\cdot5}$	$Qz_{10\cdot0}$	(Ne_{85} Kp_{15}) Kenya	associated feldspar anorthoclase or anorthoclase/sanidine
19	$Ne_{81\cdot3}$	$Kp_{12\cdot7}$	$Qz_{6\cdot0}$	($Ne_{86\cdot5}$ $Kp_{13\cdot5}$) Sardinia	
20†	$Ne_{82\cdot0}$	$Kp_{12\cdot8}$	$Qz_{5\cdot2}$	($Ne_{86\cdot5}$ $Kp_{13\cdot5}$) Dunedin	
21	$Ne_{84\cdot9}$	$Kp_{11\cdot9}$	$Qz_{3\cdot2}$	($Ne_{87\cdot7}$ $Kp_{12\cdot3}$) Vesuvius	
22	$Ne_{84\cdot4}$	$Kp_{12\cdot7}$	$Qz_{2\cdot9}$	($Ne_{86\cdot9}$ $Kp_{13\cdot1}$) Madras	
23†	$Ne_{80\cdot4}$	$Kp_{16\cdot4}$	$Qz_{3\cdot2}$	($Ne_{83\cdot1}$ $Kp_{16\cdot9}$) Burma	
24†	$Ne_{83\cdot3}$	$Kp_{13\cdot8}$	$Qz_{2\cdot9}$	($Ne_{85\cdot8}$ $Kp_{14\cdot2}$) Burma	

† New analyses of tables 1 and 2, this paper.

In view of the sodic character of the nepheline as judged by its refractive indices, both this mineral and the accompanying feldspar were isolated and analyzed by Mr. Scoon, the results being set down in table 2, nos. 2 and 3.

In figure 1 these two analyses are plotted as A and A″, the felsic composition of the rock as given by the mode being indicated on the tie line A A″ at R.

In the light of the new data now presented, the discussion of nepheline composition in relation to alkali feldspar environment may now be resumed.

The list of 24 analyses (expressed in terms of Ne, Kp and Qz) of nephelines are set out in table 3.

To this list may be added examples from other well-known alkali syenite areas, Miask, Ditro, and Langesundsfjord. They are as follows:

Miascite, Miask	$Ne_{75.4}\ Kp_{20.0}\ Qz_{4.6}$	(Karandejew, 1913)
	$Ne_{77.0}\ Kp_{20.2}\ Qz_{2.8}$	(Morozewicz, 1907)
Ditroite, Ditro	$Ne_{75.8}\ Kp_{21.3}\ Qz_{2.9}$	(Morozewicz, 1930)
	$Ne_{74.8}\ Kp_{18.5}\ Qz_{6.7}$	(Mauritz, 1910)
Langesundsfjord	$Ne_{75.2}\ Kp_{19.1}\ Qz_{5.7}$	(Foote and Bradley, 1911)
	$Ne_{74.4}\ Kp_{19.3}\ Qz_{6.3}$	(Morozewicz, 1899)

The alkali feldspar associations of the assemblages represented by miascite and ditroite are known to be albite and microcline-microperthite, and though the associations of the Langesundsfjord nephelines are not stated in the reports of the analyses, it seems clear that they must belong to the nepheline syenite pegmatites (Eikaholmen and Låven) which are distinguished by the association of microcline-microperthite and albite as distinct from the high temperature (anorthoclase) associations of the normal lardalites.

These lists when viewed in the light of the feldspar parageneses present some obvious contrasts.

The remarkable approach to convergence on a figure near Morozewicz's normal formula $Ne_4Kp_1Qz_1$ ($Ne_{75.1}\ Kp_{20.9}\ Qz_{4.0}$ wt.%) is shown not only by his own examples from the Mariupol district but also by the nine examples from Ontario. The associated feldspars are albite ± microcline and the deep-seated host rocks show a potash-soda ratio varying from 1:2.3 to 1:23.6 (nos. 2 and 4 respectively). The same convergence is shown by other host rocks in the lists which carry albite and microcline.

On the other hand, in the three volcanic phonolites (Dunedin, Kenya, and Sardinia) carrying feldspars of the sanidine-anorthoclase series, the nephelines are systematically more sodic despite the fact that the host rocks are more potassic than many of the deepseated examples.

This is given graphical expression in figure 2.

We know further from von Eckermann's studies at Alnö that the potassic juvites and foyaitic ijolites which carry a single alkali feldspar (orthoclase ? sanidine) have nephelines with a more strongly potassic character. An example from the juvite of Ås at Alnö has nepheline $Ne_{64}\ Kp_{36}$ and foyaitic ijolite from N. E. of Smedsgården has an even more potassic phase ($Ne_{59}Kp_{41}$) (von Eckermann, 1948, p. 50-51).

Adjustment of composition of nepheline with changing composition of host rock belongs characteristically, then, to assemblages carrying a single alkali feldspar of a type indicating a higher temperature of environment at the close of effective crystallization.

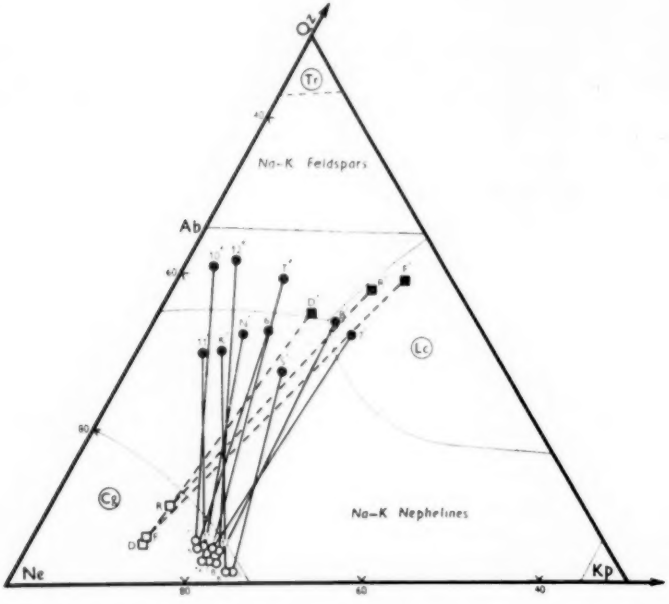

Fig. 2. Plot of analyses of nephelines and salic normative constituents of their host rocks in the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2.

Filled circles—host rocks carrying alkali feldspars, albite ± microcline.

Filled squares—host rocks carrying alkali feldspars of the anorthoclase-sanidine series. 6′, 7′, 10′, 11′, 12′—mariupolite series, Azov; B′—nepheline syenite, Blue Mt., Ontario; K′—mariupolite, Koedoeslaagte, Vaal River, Transvaal; N′—nepheline syenite gneiss, Tambani, Nyasaland; S′—grennaite, Norra Kärr, Sweden; T′—ditroite, Ditro, Transylvania. D′—phonolite, Dunedin; R′—phonolite, Kenya; F′—phonolite, Sardinia.

Recrystallization processes, whether of autometamorphism or metamorphism long subsequent, which at lower temperatures give rise to albite-microcline assemblages from a single high temperature feldspar appear to effect corresponding changes in the nepheline phase if this is not already in the convergence field indicated by the analytical data.

The mechanism of this process is perhaps twofold—a production of a less siliceous nepheline and an adjustment in soda-potash ratio to within the limits of the convergence field.

The process may be illustrated for a sodic nepheline of a phonolite with a tie line indicated in figure 3 as 1—1′—1″, this paragenesis by low temperature recrystallization being adjusted to 3—1′—3″.

The change may be expressed in terms of phase equilibria as equivalent to removal of albite, and the adjustment to a more potassic nepheline (3) by a reaction between the nepheline and the feldspathic phases, the limits of transformation (volcanic-metamorphic) being effectively as follows:

$$\underbrace{(Na,K)AlSiO_4 + (K,Na)AlSi_3O_8}_{\text{nepheline} \quad \text{anorthoclase}} \rightarrow \underbrace{(K,Na)AlSiO_4 + (Na,K)AlSi_3O_8}_{\text{nepheline} \quad \text{albite} + \text{microcline}}$$

volcanic assemblage — metamorphic (or plutonic) assemblage

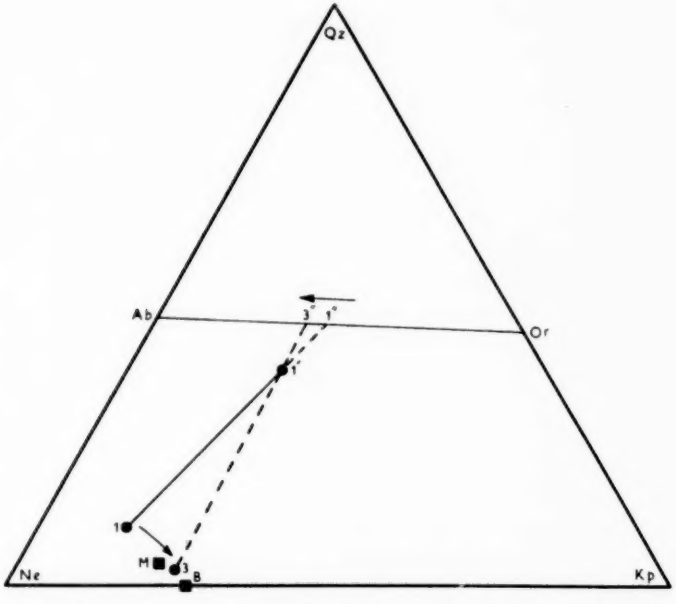

Fig. 3. Plot of tie line of volcanic phonolite (1–1′–1″) and corresponding metamorphic derivative (3–1′–3″) = nepheline gneiss, in the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2. M and B nepheline formulae of Morozewicz and Buerger respectively. For discussion of this diagram see text.

As interpreted for the metamorphism of the two rocks discussed in the preceding account (the Dunedin phonolite and the Burma ijolitic nepheline syenite), the corresponding changes are indicated in figure 1. D—D′—S (anorthoclase) → Y—D′—Y″ (albite and microcline) for the phonolite, and for the Burma rock, assuming R represents the effective composition of the host rock, A—R—A″ (orthoclase cryptoperthite[1]) → X—R—Ab in which the metamorphic assemblage carries albite only as the feldspathic phase.

[1] More information on the high temperature character of the Burma nepheline syenite may become available with a thermal and X-ray study of this cryptoperthite. It may be that the latter crystallized as a homogenous sodic member of the anorthoclase-sanidine series above the anorthoclase inversion, but unmixed above that temperature.

Finally, to take specific analyzed examples of quasi-heteromorphic feldspar-felspathoid assemblages illustrating composition differences of the nepheline phase (as revealed in refractive values), reference may be directed to the sets of rock pairs of table 4—respectively, a phonolite and its heteromorph, a nepheline gneiss; a kenyte and the corresponding albite-microcline-foyaite.

The evidence of adjustment of nepheline composition to temperature revealed in the contrasted assemblages of the feldspathoidal rocks makes clear the desirability of a systematic experimental hydrothermal study of the subsolidus equilibria in the soda-potash nepheline series, and in the extended system $NaAlSiO_4$—$KAlSiO_4$—SiO_2; for it is from such a study that alkali feldspar-nepheline equilibria might eventually be traced through successive temperature stages and so illuminate broad fields in the realm of the feldspathoidal rocks.

TABLE 4

Heteromorphic Nepheline Assemblages
(Volcanic and Metamorphic or Plutonic)

	1	2	3	4
SiO_2	54.81	55.99	53.98	54.57
Al_2O_3	19.10	20.18	19.43	20.32
Fe_2O_3	1.57	4.19	4.39	3.53
FeO	3.52	3.25	2.05	3.15
MgO	0.96	0.33	1.07	0.26
CaO	1.81	2.29	2.04	1.67
Na_2O	6.88	6.85	8.81	8.78
K_2O	5.41	5.59	5.27	5.82
H_2O+	3.63	0.63	1.66	0.74
H_2O-	0.57		0.13	
TiO_2	0.82	0.29	0.57	0.56
P_2O_5	0.22	0.19	0.30	Nil
MnO	0.27	—	0.26	0.21
Rest	0.14	0.06		0.27
	99.71	99.84	99.96	99.88

	Coordinates in the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2				
	Rock				
	Ne	Kp	Qz		
1	39.7	22.6	37.7		
2	38.7	23.4	37.9		
	Nepheline				
1	76.5	13.5	10.0	(Ne_{86} Kp_{15})	ω 1.535, ε 1.531
2	———				ω 1.540, ε 1.536
	Rock				
3	46.8	21.8	31.4		
4	45.8	23.1	31.1		
	Nepheline				
3	———				ω 1.535, ε 1.531
4	74.7	20.9	4.4	(Ne_{78} Kp_{22})	

1 Phonolite, Nairobi-Nyeri Road, Kenya (Bowen and Ellestad, 1936, p. 365 [*anorthoclase*]).

2 Hastingsite nepheline gneiss, Makaraingo, Madagascar (Lacroix, 1922, p. 505 [*albite, microcline*]).

3 Kenyte, central core of Mount Kenya, Teleki Valley, Kenya (Smith, 1931, p. 246 [*anorthoclase*]).

4 Trachytoidal foyaite, Mariupol, Azov, Russia (Morozewicz, 1930, p. 377 [*albite, microcline*]).

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University of Cambridge
Cambridge, England

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RADIOACTIVITY OF THE SPRING WATERS OF HOT SPRINGS NATIONAL PARK AND VICINITY IN ARKANSAS

P. K. KURODA, P. E. DAMON, AND H. I. HYDE

ABSTRACT. The radon content of the waters of Hot Springs National Park have been redetermined and compared with the work of Boltwood (1905) and Schlundt (1935) previously reported in this JOURNAL. Thoron, previously not detected, was measured by a new technique. The radon content of the warm waters at Hope, Arkansas and Caddo Gap were also determined. Unusually high radon content of the waters at Potash Sulphur Springs, Arkansas can be correlated with the presence of a uranium, vanadium, niobium deposit in this vicinity. The radon content of the waters of Hot Springs National Park is derived, at least in part, from radium-bearing tufa.

The radioactivity of the spring water of Hot Springs National Park, Hot Springs, Arkansas was first measured by B. B. Boltwood (1905). He reported the radon content of 44 hot springs and 2 cold springs in this area. One of the most interesting results of his investigation was the demonstration of marked variations in the activity of the water from such a closely related series of springs. In their general chemical characteristics the waters from the different springs showed a marked resemblance to one another, and the great variation in the activity of the different waters was entirely unexpected. Although Boltwood did not carry out his measurements in the field, he emphasized that these variations were in no way due to the conditions under which the particular samples were collected and tested. Duplicate samples collected at different times and by different persons gave closely agreeing results. Boltwood also stated that it was impossible to establish any connection between the temperature, flow, location, or chemical composition of the waters of the springs and the observed differences in the radioactive properties. It was also pointed out by Boltwood that the fact that two cold springs showed rather high radon content seems to indicate that the thermal qualities of the waters and their radioactive properties are due to quite independent causes.

The radioactive properties of the waters of Hot Springs, Arkansas were investigated again by H. Schlundt (1935). A Wulf quartz-fibre electroscope fitted with an ionization chamber of 1175 cc capacity served for the field measurement of water samples. Radon determinations were made by the circulation method. Thus the first field measurement of the radioactivity of the waters of Hot Springs, Arkansas was made by Schlundt, but unfortunately most of the hot springs had been covered by terracing shortly before his investigation. Schlundt reported the radon content of only 5 hot springs, one cold spring, and the water of the main reservoir. No thoron was detected in the air in the collecting reservoir taken at a level of about one foot above the surface of the water. The presence of radium in the water was established definitely by Schlundt for the first time. The three values averaged 1.38 x 10^{-12}g radium per liter. Schlundt also pointed out that some tufa samples showed high contents of radium, but did not contain equilibrium amounts of uranium.

The authors redetermined the radon and thoron content of the waters of Hot Springs National Park in the fall of 1952. Most of the springs had been deeply covered under the ground in 1932 to prevent pollution. However, through the courtesy of the National Park authorities most of the springs were uncovered during this investigation, and the water was sampled at or near the orifice of each spring. In some cases the sampling was difficult and not without hazard.

The geology of the Hot Springs has been studied by Purdue and Miser (1923) and Bryan (1922). There are other thermal springs and unusually warm wells in the region, providing evidence for Bryan's belief that the hydrothermal activity is not a local phenomenon but extends over a wide area. The radioactivity of some of these warm waters has also been determined by the authors. The geology of the Hot Springs area has been reinvestigated recently by University of Arkansas geologists (Arndt and Stroud, 1952) and will be published in the near future. The U. S. Geological Survey has provided complete chemical (including trace elements) analysis of 13 thermal springs and 13 cold springs in connection with this work. It is anticipated that this information will be published in the near future.

Much of the early interest in the radioactivity of Hot Springs resulted from the balneological usage of natural mineral waters. The use of uranium in nuclear reactors has produced a renewed interest in the radioactivity of spring waters as an indicator of possible subsurface uranium deposits. Investigation of the origin of the radioactivity of the waters of Hot Springs National Park led to the discovery during the summer of 1950 (Stroud, 1951) of a uranium-vanadium-niobum deposit associated with the perimeter of the nepheline syenite stock at Potash Sulphur Springs only 5 miles distant from the Hot Springs. The radioactivity of the spring waters at Potash Sulphur Springs (now Wilson's Springs) has also been studied by the authors and is reported in this paper.

Study of the radioactivity of natural waters is of interest aside from these practical applications. A unique insight is provided into the migration of elements not only in the hydrosphere but (since radon and thoron are gases) into the atmosphere as well (Damon and Kuroda, 1953).

An I M-type fontactoscope of the Scientific Research Institute, Tokyo, Japan (Kuroda and Yokoyama, 1953), was used for the measurement of the radon content of waters. A new instrument was also developed—the scintillation tube (Damon and Hyde, 1952)—and used for the detection of thoron and radon. The I M fontactoscope is simple and portable, whereas the scintillation tube was mounted with other equipment in a surplus Army truck used as a mobile radiometric laboratory. The scintillation tube has a much greater sensitivity for thoron, even in the presence of radon. With this instrument thoron was detected in the waters of Hot Springs National Park for the first time.

Both instruments were calibrated against U. S. Bureau of Standards standard radium solutions. The I M fontactoscope was also calibrated against the radon standard of the Institute of Scientific Research, Tokyo. The results of the intercalibration are given in table 1. The agreement is excellent.

TABLE 1

Intercalibration of the I M Fontactoscope against Standards Prepared Independently in the United States and in Japan

Standard	Sensitivity constant of the instrument, obtained from the value of ionization current. (10^{-9} curie/division/minute)	
U. S. A.	0.148 0.143 0.145	average, 0.145
Japan	0.145 0.146 0.144	average, 0.145

As shown in tables 2a and 2b, there may be a large loss of radon during the sampling process, especially if the water cannot be sampled at the orifice. Even if the water is sampled directly at the orifice, some of the radon may escape.

Although the sampling of the water introduces the greatest source of error, the reproducibility of results is excellent under favorable conditions with careful sampling to avoid emanation loss (table 3).

TABLE 2A

Loss of Radon in Sampling Process
Sample: Cups Spring (Spring no. 29)

Method of Sampling	Radon Content (10^{-9} curie/l)	Loss of Radon (percent)
1 Direct sampling at orifice	8.76	—
2 Sample taken carefully into a graduated cylinder and to the instrument	7.60	13
3 Sample taken into a bottle, then to a graduated cylinder, and finally to the instrument	6.12	30
4 Sample taken into a bottle leaving an air space, then to a graduated cylinder, and finally to the instrument	4.92	44

TABLE 2B

Loss of Radon when Spring Water Flows
Sample: Cups Spring (Spring no. 29)

Sample taken	Radon Content (10^{-9} curie/l)	Loss of Radon (percent)
1 At the orifice	7.40	—
2 15 feet from the orifice	2.50	66
3 30 feet from the orifice	0.65	91
4 50 feet from the orifice	0.20	97

TABLE 3

Reproducibility of Radon Determination

Sample	Radon Content (10^{-9} curie)
Drinking Springs	
(National Park Administration Building)	0.74
	0.79
	0.79
	0.79
Exhibition Spring no. 2	1.66
	1.60
	1.58
	1.55
	1.67

RESULTS AT HOT SPRINGS NATIONAL PARK

The radon content of Hot Spring Waters determined by Boltwood, Schlundt, and the authors is shown in table 4. The minimum and maximum ratios of Boltwood's values to ours are 0.17 and 33. Our values indicate an average radon content twofold higher than that determined by Boltwood. Schlundt made only a few determinations. However, our value for the radon content of the main reservoir is 1.75 times the value determined by Schlundt.

It is possible that extensive changes in the collecting system, which were completed after Schlundt's work, may have caused a change in the radon content of the spring waters. Schlundt has demonstrated the existence of tufas at Hot Springs, containing a high radium content[1] which would supply at least part of the radon content of the spring waters. Changes affecting these tufa deposits would obviously result in a change in the radon content of the waters. Although sampling errors may account for some of the differences between our results and previous results, there is little doubt that there have been large changes in the radon content of certain of the Hot Springs. As can be seen in table 5, there also have been rather large changes in the temperatures of individual springs.

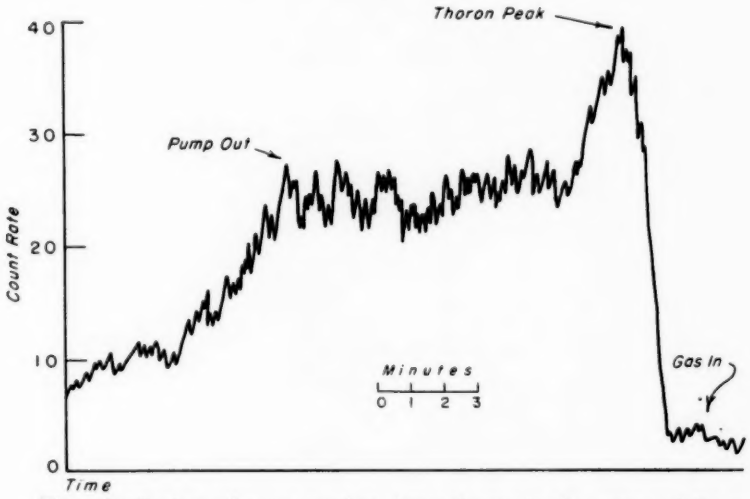
[1] The radium content of the tufa deposits is now being investigated, and the results will be correlated with the radon content of the water. One of the authors, P. K. Kuroda, has found a deficiency of short-lived decay products in the spring waters. This indicates that either the decay products are deposited in transit or that the source is not deep.

TABLE 4

The Radon Content of Spring Waters of Hot Springs National Park, Arkansas

Haywood Number (1902)	Name of Spring	Boltwood (10^{-9} curie/l) (1905)	Schlundt (1932)	Authors (1952)
1	Egg	0.887		2.13
2	Arsenic	0.493		
3	Arlington	1.037		3.70
4	Cliff	0.347		
5	Avenue	0.887		0.21
6	Boiler House	1.360		
7	Imperial Spr. (North)	9.03		30.5
8	Crystal	0.466		0.61
9	Rector	0.503		2.21
10	Cave	0.126		
11	Little Iron (North)	0.490		
12	Little Geyser	0.231		
13	Little Iron (South)	0.513		
14	Ral	1.85		
15	Big Iron	0.052		
16	Imperial (South)			
17	Arsenic (North)	0.813		0.87
18	Hitchcock	1.666		2.51
19	Sumpter			
20	Superior (North)	0.983		
21	Alum	0.401		
22	Superior (South)	0.996		
23	Twin (North)	2.224		0.38
24	Twin (South)	1.860		3.67
25	Old Hale	0.350		0.72
26	Palace	0.116	0.199	
27	Tunnel	1.414		3.24
28	Maurice	0.520		0.33
29	Dripping (Cups)	0.262		8.62
30	Arch			
31	Haywood (Display Cups)	0.167		.80
32	J. W. Noble (Display 2)	0.748		1.66
33	Lamar	0.150		
34	Wiley (Display 1)	0.299	0.43	0.14
35	Ed Hardin	0.799		0.22
36	Eisele	0.167		
37	Stevens	0.282		
38	Horse Shoe	0.180	0.20	0.34
39	Army and Navy	0.017	0.125	
40	W. J. Little (A&M)			
41	Mud	0.051		
42	Magnesia	0.272		0.58
43	Reservoir	0.027		
44	Liver	0.592		
45	Kidney	3.631		
46	Fordyce	0.439	0.499	0.81
	New Spring			0.40
	New Spring			13.5
	No Name	0.503		3.36
	Fordyce Well	3.308		
	Spring in Maurice			0.26
	Main Reservoir		.46	0.82

Figure 1. **TRACE OF THORON PEAK 30 SECONDS AFTER SAMPLING**
MAURICE CUPS SPRING, HOT SPRINGS, ARKANSAS



The scintillation tube was used to detect thoron in the waters of the main reservoir and the various fountains (table 6). Figure 1 shows the recorder tracing of the thoron and radon contents of Maurice Cups Spring. Figure 2 shows the recorder tracing of the radon content after allowing 7 minutes for the thoron to decay before releasing the gas into the scintillation tube by vacuum transfer. This provided conclusive evidence for the existence of the gas thoron in the hot waters at Hot Springs National Park.

For contrast, the radon content of cold springs in the vicinity of the hot springs is given in table 7.

Figure 2. **RADON AND RADIUM TRACE AFTER 7 MINUTES**
MAURICE CUPS SPRING, HOT SPRINGS, ARKANSAS

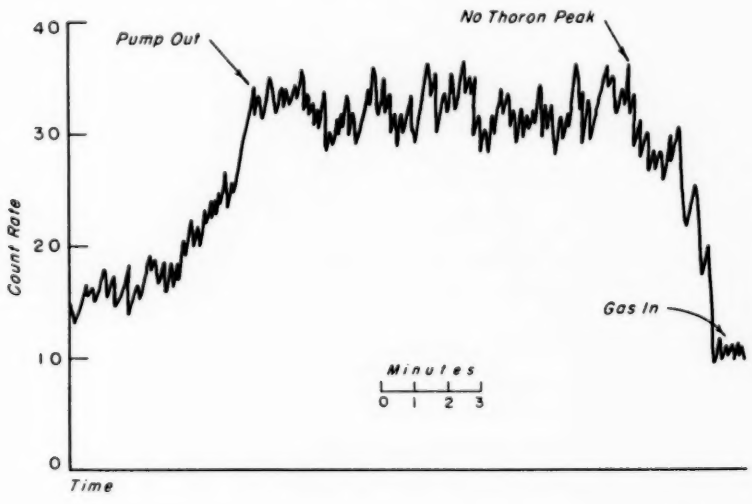


TABLE 5

Temperature of the Hot Springs at Hot Springs National Park

Haywood Spring Number	Arkansas Geological Survey (Branner, 1890)	Haywood (1900)	Haywood (1901)	Hamilton (1932)	Present Temp. (1952) (°F.)
1	144.7	143.4	143.1		143.6
2		125.4	129.0	130.1	
3		143.1	142.3	140.0	144.0
4		132.6	126.3	135.0	
5		142.5	143.4	142.0	143.0
6		135.5	136.9	135.0	137.5
7		140.2	141.4		143.9
8		95.4	97.2	142.0	
9	139.28	142.0	144.3	144.0	142.2
10		135.3	135.0	140.0	
11			134.2	148.0	142.2
12		97.2	97.2		
13		133.3	see 11		142.2
14	139.28	141.6	145.0		
15	146.48	147.0	147.0	148.0?"	142.2
16		141.4	141.6		
17		131.7	133.5	132.0	134.5
18		135.2	135.2	127.0	139.2
19		133.5	133.0		
20		115.3	112.1	112.5	
21	115.88	109.9	114.8		
22		134.8	133.7	133.0	
23		143.6	144.3	122.0	139.3
24		144.1	140.5	136.0	129.7
25	142.9	144.8	145.2		146.0
26		146.1	142.5	146.0	
27			125.4		138.5
28			139.6		140.0
29		134.8	136.0		142.0
30		129.0	125.4		
31		124.5	124.5	130.0	129.2
32		114.8	115.7	113.0	126.5
33		118.9	120.6		
34		118.2	117.1		135.5
35		102.2	109.4		
36		120.0	119.8		
37		127.2	126.7		
38		137.8	139.6		140.5
39		142.5	142.5		
40		120.0	120.0		
41		116.2	118.9		
42	124.88		136.9	141.0	141.5
43			115.2	122.0	
44			46.0		
45			55.4		
46			124.7	135.0	
47*				137.5	143.0
48*					143.9
49*				138.0	141.9
50*				145.0	
X*				133.0	
Y*				118.0	
Z*				138.0	
W*				115.5	
V*				122.0	142.0

* Present no.

TABLE 6

The Emanation Content of Main Reservoir, Artificial Fountain, and Drinking Taps

	Name	Radon Content (10^{-9} curie/l)	Thoron Content (10^{-9} curie/l)
1	Main reservoir	0.82; 0.80	< 0.3
2	Drinking spring at National Park Administration Building	0.78	< 0.3
3	Drinking spring no. 2 at National Park Administration Building	0.78	< 0.3
4	Fountain in front of National Park Administration Building	0.09	—
5	Drinking spring in front of Maurice baths	0.65	0.90
6	Drinking spring near Exhibition Springs	0.82	0.48
7	Drinking spring near the Historical Park	0.41	—

TABLE 7

The Radon Content of Cold Springs in the Vicinity of Hot Springs

	Source	Date	Radon Content (10^{-9} curie/l)
1	Wilson Spring no. 1	Sept. 13	1.83
2	Sleepy Valley no. 2	17	2.80
3	Sleepy Valley no. 1	17	4.37
4	Iron Spring	18	0.41
5	Magnesia Spring	20	7.28
6	Spring no. 3, Camp	20	6.52
7	Happy Hollow Spring	20	0.74
8	Artesian Well at Whittington Park	23	0.03
9	Three Sister Spring no. 1	24	0.10
10	Three Sister Spring no. 2	24	0.26
11	Three Sister Spring no. 3	24	0.24
12	Whittington Spring	26	0.36

We have attempted to correlate the radon content of the spring waters with temperature, rate of flow, chemical composition, and geographical location[2] within the spring area. We find no clear correlation, which is in agreement with the conclusions reached by Boltwood. We are now investigating the longer-lived decay products of uranium and thorium and expect to report this work at a later date.

RADON CONTENT OF THE WATER AT POTASH SULPHUR SPRINGS

The many springs near the Potash Sulphur Spring (now Wilson's Spring) are of great interest because of the uranium-vanadium-niobium prospect in the immediate vicinity.

We have divided the springs geographically into three groups—A, B, and C. Group A borders the prospect area to the south, whereas Group B borders to the north. The springs in Group C issue from syenitic rock along Potash Sulphur Creek, west of the prospect, but not directly bordering it. Also included in table 8 is the radon content of drill holes directly within the prospect area.

[2] Prof. R. H. Arndt of this University has recently discovered an orthogonal fracture system which seems to have some control over the temperature and flow of the springs, and perhaps also the radon content.

TABLE 8

Radon Content of the Water at Potash Sulphur Springs

Name	Date	Radon Content (10^{-9} curie/l)
Group A Springs bordering prospect area to the south		
A1	Oct. 18, 1952	8.57
A2	18	10.8
A3	16	8.97
A4	18	14.2
Group B Springs along the creek, north side of the deposit		
B1 (source of creek)	Oct. 15, 1952	17.6
B2	19	6.33
B3	16	28.1
	19	29.9
	19	25.4
B4	16	8.0
B5	19	16.8
B6	15	15.4
Group C Springs along the river near the picnic ground		
C1	Oct. 16, 1952	0.79
C2	16	1.61
C3 (Spring House)	18	2.35
C4	18	1.11
Drill hole no. 2	18	10.0
Drill hole no. 1 prospect area	15-18	56-79

The uranium content of selected samples from the prospect area is as high as 0.6 percent U_3O_8; however, the bulk material averages around 0.02 percent U_3O_8. This is roughly tenfold higher than a typical uranium-bearing black shale (Polk Creek shale). It can be seen that there is a very apparent effect of the uranium deposit on the spring waters bordering the prospect. However, the spring waters not in direct contact with the prospect are not anomalous.

No thoron could be detected in the water from Spring B6.

RADON CONTENT OF THE WATERS AT CADDO GAP, ARKANSAS

A group of springs issues from the novaculite formation into the bed of the Caddo River at Caddo Gap, Arkansas. There is also one spring on the shore of the river, and one spring issues from the Novaculite, 2 miles southwest of Caddo Gap (Barton's Spring).

The chemical composition of the warm water at Caddo Gap is very similar to that of the waters at Hot Springs National Park. We have determined the radon content of the 2 warm springs which could be conveniently sampled, and also a group of cold springs for contrast (table 9).

TABLE 9

Radon Content of the Warm and Cold Spring Waters at Caddo Gap, Arkansas (Oct. 22, 1952)

Spring designation	Radon (10^{-9} curie/l)	Temp. °F.
Warm Spring on Shore of Caddo River	0.18	96.8
Barton's Warm Spring	0.85	89.6
Swanson Well Water	0.34	64.4
Dripping Spring	0.53	59.0
Creek Spring near Prospect Cave	0.95	58.1
Prospect Cave	0.13	58.1
Church Camp Spring	0.31	64.8
Seep Springs in Creek near Church Camp	1.85	60.8
McLean's Health Spring	0.15	64.4

RADON CONTENT OF THE WARM WATERS OF DEEP WELLS AT HOPE AND PRESCOTT, ARKANSAS

The deep wells at Hope and Prescott are saline and contain large amounts of boron (4.6 ppm) and fluorine (2.8 ppm). We are investigating the waters of this area thoroughly because there is some possibility that at least part of the water is of juvenile origin. It can be seen from table 10 that the radon content is quite low for the deep, warm, saline waters pumped from the Tokio formation and is considerably higher for the waters from the overlying formations.

TABLE 10

Radon Content of Deep Wells at Hope and Prescott, Arkansas

Well Designation	Depth in feet	Formation	Radon (10^{-9} curie/l)	Chlorine (ppm)	Total solids (ppm)	Temperature °F.
Hope (Airfield)	207	Midway	1.37	5.5	280	66.2
Hope (DW 2)	620	Nacatoch	1.76	36	374	76.6
Hope (DW 3)	620	Nacatoch	1.88	41	386	76.6
Hope (WW11)	1050	Ozan	0.08	114	545	86.4
Hope (DW 1)	1480	Tokio	0.09	292	1060	99.0
Hope (DW 5)	1500	Tokio	0.06	320	1120	93.6
Prescott (4)	1070	Ozan-Tokio	0.05	373	1280	88.7
Prescott (2)	325	Nacatoch	1.65	14	321	71.6
Prescott (3)	325	Arkadelphia Marl-Nacatoch	1.66	18	322	69.8

CONCLUDING REMARKS

We have measured the radon content of a large number of warm and cold springs in the region around Hot Springs National Park. We have also measured the radon content of waters known to issue directly from a deposit containing uranium.

The hot waters are extremely variable in radon content (0.1 to 30 millimicrocuries per liter) possibly because each spring has its own radium-bearing tufa—source of radon. The average radon content is about 0.8 millimicrocuries per liter.

The cold waters are also extremely variable (0.1 to 7.3 millimicrocuries per liter) and average about the same as the hot springs.

The spring waters issuing directly from the border of the uranium-vanadium-niobium prospect at Potash Sulphur Springs average about 15 millimicrocuries per liter radon and are more uniform in radon content (6 to 40 millimicrocuries per liter).

In addition to the purely scientific interest in the radioactivity of natural waters, it is quite apparent from our work that the information can be applied to the search for fissionable materials.

ACKNOWLEDGMENTS

Acknowledgment is made of the valuable cooperation and courtesy, in the work at Hot Springs National Park, of D. S. Libbey, superintendent of the Park; of the Rangers stationed in the Park; and of the staff members, who demonstrated continuously their willingness to help.

Sincere appreciation is extended to Charles Wilson of Potash Sulphur Springs (now Wilson's Springs) and to members of his family for access to their property and for their kindness and encouragement.

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UNIVERSITY OF ARKANSAS
FAYETTEVILLE, ARKANSAS

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HYDROXYL AND WATER IN PERLITE FROM SUPERIOR, ARIZONA

W. D. KELLER and E. E. PICKETT

ABSTRACT. Infrared absorption spectra taken of pulverized perlite from a deposit at Superior, Arizona show monomeric hydroxyl and hydrogen-bonded water which are conventionally reported in chemical analyses as water lost on ignition.

The structure of the perlite is presumed to be a 3-dimensional network of Si,Al-O tetrahedra similar to that ascribed, from X-ray diffraction patterns, to artificially manufactured glass. By interposing metallic cations within holes in the glass framework, and allotting hydrogen to OH and hydrogen bonding, the architecture of the perlite is inferred. The presence of OH and hydrogen-bonded water in the inferred structure explains the relatively low temperature of liquefaction of the perlite when it is expanded or "popped" by heat processing, and the subsequent rise in fusion temperature and viscosity after the water is driven off.

INTRODUCTION

Volcanic glasses regularly contain water which remains incorporated after drying at 100°C. but is driven off, almost completely, upon heating to the fusion temperature of the glass. Washington (1917) reported the average water content of 41 obsidians as 0.53 percent. Johannsen (1932, p. 285) recorded the water in pitchstones held above ordinary room temperature as ranging in content from below 5 percent to above 10 percent, and in perlites from 2.93 to 4.35 percent.

The way or ways in which water is held in volcanic glasses has not been clearly described, but King, Todd, and Kelley (1948) concluded after a chemical and thermal study of perlite from Superior, Arizona, that "it is considered unlikely that any large portion of the water is bound as hydroxyl groups." Morey (1938, p. 89) wrote about artificially prepared glasses, "Concerning the water and carbon dioxide in solution in the glass, we have no definite information. They are probably 'chemically combined' [quotation marks by Morey] in the glass, just as are the sodium oxide and silicon dioxide; in other words, all the components of the glass are in a mutual solution in which it is not possible to identify any one-to-one coordination between various groupings." Harrison (1947) studied the water content of plates of fused silica, Pyrex-brand glass, and other artificially prepared simple glasses by their absorption of infrared radiation, and "inferred that the water in fused silica is monomeric" (p. 366). The infrared absorption by Pyrex-brand glass occurred at longer wave lengths, however, than that by fused silica, indicating hydrogen bonding in Pyrex-brand glass.

In an effort to look further into the nature of the water in volcanic glass, an infrared absorption study was made of the perlite from Superior, Arizona, the source of that which King, Todd, and Kelley had investigated chemically. This perlite expands, or "pops," beautifully when heated (to about 1650°F.) rapidly, and thereby leaves no doubt that it contains "combined" water. An analysis of the perlite reported by King et al. shows, table 1, a water content of 3.34 percent.

TABLE 1

Chemical Analysis of the Perlite from Superior, Arizona

	Wt. percent	mol. percent	cations	oxygens	cations	oxygens
SiO_2	73.61	1.226	1.226	2.452	62.5	124.9
Al_2O_3	12.17	.119	.238	.357	12.1	18.2
Fe_2O_3	1.53	.009	.018	.027	.9	1.4
CaO	0.84	.015	.015	.015	.8	.8
K_2O	5.08	.055	.110	.055	5.6	2.8
Na_2O	2.97	.048	.096	.048	4.9	2.4
H_2O	3.34	.186	.372	.186	19.0	9.5
	99.52					160.0

Analysis reported by King, Todd, and Kelley.

Expansion of volcanic glasses upon heating is not restricted to perlite. To that point, J. Bruce Clemmer[1] wrote that "our experience based upon expansion tests on a variety of obsidian, perlite, and pitchstone samples has shown that all volcanic glasses will expand under suitable conditions of temperature and retention time." F. W. Libbey[2] wrote that " . . . . so far as my information goes we have never tested a volcanic glass that did not expand a little." Presumably the expansion of different kinds of volcanic glasses to various extents upon heating is a difference in degree but not in kind.

Kozu (1929) noted a difference, however, between pitchstone and perlite on the one hand, and obsidian on the other, at temperatures below their "explosive expansion." Perlite and pitchstone from Japan expanded slightly as they were heated to 200°C., then contracted at higher temperature a large amount which sometimes reached 10 percent in volume, and expanded explosively immediately after their contraction had reached the maximum. Obsidian (Japan) showed no contraction upon similar heating, but expanded slowly during heating up to 600°C., then expanded rapidly between 600° and 700°C., and expanded explosively at about 900°C.

LABORATORY PROCEDURE

Representative pieces of the Superior, Arizona perlite, which was furnished by Mr. J. Bruce Clemmer, were crushed to about 10-mesh size and fine. A portion was finely pulverized for differential thermal analysis and X-ray diffraction. Another portion was divided into three parts for the infrared measurements.

One of these three parts was dried at 110°C. and pulverized. Another part was expanded by dropping it into a platinum crucible which was heated over a blast lamp to about 1100°C. (L and N optical pyrometer). Presumably it would become anhydrous at this temperature.

A third part was heated to 350°C. for 4 hours, a temperature which dehydrated the perlite to a significant value, as found by King et al. They reported (1948, p. 15) that "three types of measurements agree in showing that water in perlite above about 1.2 percent is loosely held and therefore readily removable. As dehydration proceeds, the residual water is increasingly

[1] Personal letter, July 17, 1951.
[2] Personal letter, May 29, 1951.

more firmly held, and it is probable that only the more firmly held portion is effective in producing expansion of the perlite on heating." They dehydrated a sample to 1.12 percent water (below 1.2 percent) by heating it to 350°C. for one hour. Hence, by heating to 350°C. the perlite should have lost its more loosely held water and retained that which is effective in expanding it upon further heating.

After their respective heat treatments, each of these fractions was dry-ground with a mechanically operated mullite mortar and pestle until reduced to particles of the order of about 2 microns and less in diameter. This powder was stored in a desiccator over Drierite. Before measuring, it was again dried at 110°C. to drive off any moisture which might have been absorbed from the atmosphere during grinding, and was then poured directly at 110°C. into anhydrous isopropyl alcohol or into Nujol, in which it was mounted on the NaCl absorption cell of the infrared instrument. Immediately after mounting, the absorption by the sample was measured in a model IR-2 Beckman infrared spectrophotometer.

Two spectra were run on each sample; one was run on a dry powder film across the IR range from 2 to 15 microns wave length, and plotted as a dashed line; another was rerun on a thick suspension of powder in Nujol across the 2.5–3.5 micron, and in the 6–6.5 micron regions to show especially the OH and H_2O, and plotted as a solid line. Larger quantities of powder can be handled in a Nujol mull than in a dry film, and therefore they show more intensely the absorptions by water. Effort was made to work with nearly equal amounts of powder in the cell under comparable mounts, but sufficient control could not be maintained to make the analyses truly quantitative. Although they are roughly proportional, it is not certain that equal quantities of powder were in the beam for each sample.

Recent papers which discuss the determination and interpretation of infrared spectra from solids include those of Keller and Pickett, 1949, 1950; Hunt, Wisherd, and Bonham, 1950; Keller, Spotts, and Biggs, 1952; Miller and Wilkins, 1952; and Launer, 1952, besides that of Miss Harrison, 1947, already mentioned.

DISCUSSION OF THE SPECTRA

Spectrograms no. 1 to 3 show the infrared absorption by perlite from Superior, Arizona when heated respectively to 110°C., 350°C., and approximately 1100°C. The strong absorption by Nujol used as a suspending medium is indicated by an asterisk. For the purposes of this paper, attention is focussed mainly on the partial spectra drawn in solid lines across the wave lengths which are diagnostic of absorption by OH and H_2O. Wave length and wave numbers of the radiation are plotted on the abscissa, and percent transmission is on the ordinate.

The raw perlite heated to 110°C.—The full length spectrogram of raw perlite dried at 110°C., no. 1, shows little fine structure, commonly so in the case of spectra of poorly organized (crystallized) solids or glasses. The strong absorption in the range 8 to 10 microns, and near 12.5 microns, is regularly found in silicate minerals or in highly polymerized silica tetrahedra (Keller,

Spotts, and Biggs, 1952, p. 468). This similarity is to be expected from the chemical composition of the perlite. Some water is indicated by absorption in the 6.1 and 2.8 micron regions, but the latter absorption includes also (probably predominantly) hydrogen-bonded (polymeric) OH groups.

The absorption by water and OH groups in these regions is shown more clearly by the solid line representing the measurement of the concentrated suspension in Nujol. Strong absorption begins at about 2.7 microns and continues to a maximum at 2.8 microns. This range (2.7–2.8) includes the absorption by monomeric OH which characteristically reaches a maximum at 2.75 microns but diminishes almost to nil at approximately 2.8 microns. Typical absorption by monomeric OH is exhibited by kaolinite, spectrogram no. 4. In monomeric OH the structure is interpreted as an atom of H oscillating along a stretching bond between it and the oxygen to which it is attached.

The occurrence of some monomeric OH in the raw perlite is therefore indicated. The absolute quantity of monomeric OH, as well as its ratio to hydrogen-bonded OH, are unknown, but the amount of monomeric OH must not be dominant because the absorption curve shows no tendency to rise between 2.75 and 2.80 microns.

That hydrogen-bonded OH and H_2O constitute a major part of the water in the Superior perlite is indicated by the relatively large area included within the curve between 2.7 and 3.25 microns. The strong absorption by Nujol, starting at 3.25 microns, prevents a normal return of the curve to baseline as the effect of OH absorption diminishes. By extrapolating the curve upward to base (see dotted line), and by integrating the area within the absorption part of the curve, one gets a better idea of the relative amount of absorption due to the 3.34 percent of water in the perlite.

The absorption in the region of 6.14 microns is due to water in the H_2O form. Minerals and chemicals which contain "water of crystallization" as in gypsum, $CaSO_4.2H_2O$, melanterite, $FeSO_4.7H_2O$, hypo, and many others (Miller and Wilkins, 1952; Keller, Spotts, and Biggs, 1952), show absorptions in the 2.8 and 6.1 micron regions. Liquid, molecular water also shows this absorption, and therefore, unfortunately, infrared absorption spectra cannot in our present state of knowledge be used to differentiate between mechanically trapped H_2O, and H_2O which forms an integral part of the crystal, as in gypsum, or to recognize hydrogen-bonded water per se.

From another approach, however, entirely independent of infrared absorption, it may be inferred with reasonable assurance that a significant part of the water in perlite is not mechanically trapped. That most, if not all, of the water must be bonded to, and act as links or bridges (Buerger, 1948) between the oxygens of adjacent silica (an alumina) tetrahedra in the glass structure is indicated by its effect on the relatively low temperature of liquefaction (fusion) of the perlite during its cellular, pumice-forming expansion (popping) when artificially heated.

The Superior perlite expands voluminously into the pumiceous globules and particles characteristic of the expanded perlite of industry over a temperature interval dependent upon particle size and the kind of exposure to high temperature, and a well-expanded glassy froth is developed from it by

heating in a laboratory furnace at 900°C. (approx. 1650°F.). Vesiculation in the perlite can be seen under the microscope after heating to as low as 600°C. After the perlite has been expanded and the water driven out thereby, the temperature required to fuse it rises very notably. The fusion of an anhydrous glass occurs also over a temperature interval, as is well known, and can not be delimited sharply, but measurements which can be made on it are comparable in accuracy to those on the fusion of the raw perlite. Mr. Kirby Allen, in the laboratory of the A. P. Green Fire Brick Company, Mexico, Missouri, kindly heated specimens of the expanded Superior perlite at elevated temperatures and reported as follows[3]: "Our observations would be that the calcined (expanded) material begins to melt, fuse, or stick together somewhere around 2050°F. to 2090°F. (1121°C. to 1143°C.), but it has not exactly melted or turned to a glass even at 2190°F. (1199°C.). Even at 2400°F. (1316°C.) the material did not fuse together entirely."

Definitely the raw, water-containing perlite is sufficiently fluid at 900°C. to blow large bubbles in itself, but after dehydration it is so viscous at even 1300°C. that it does not run together completely. A rise in the "melting temperature" somewhere between 400°–700°C. accompanies the loss of about 1.12 percent of "combined water" (King, Todd, and Kelley found that this amount of water, or even less, produced the expansion of the perlite).

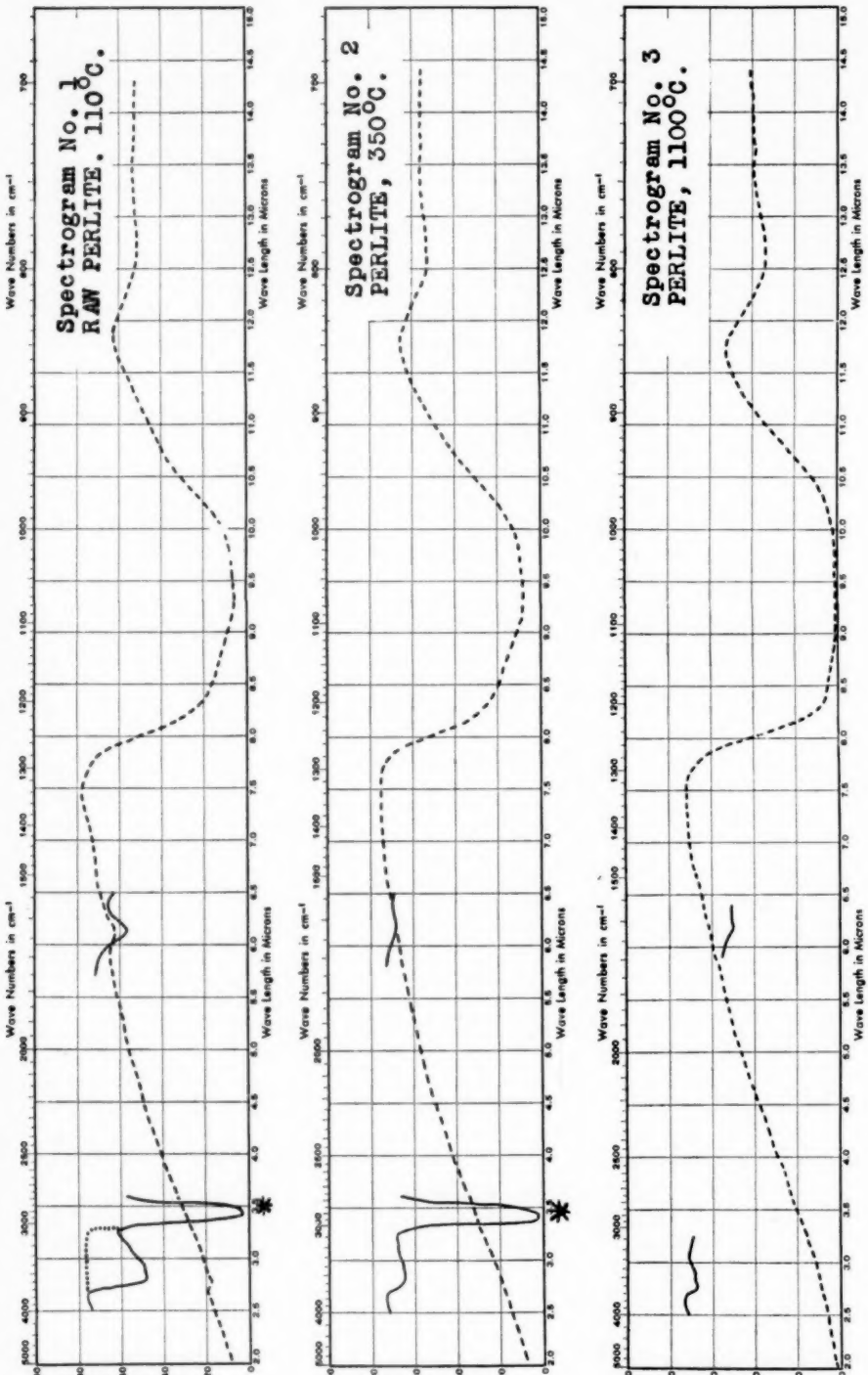
If the water in the perlite were mechanically trapped in tiny vesicles, i. e., without some kind of chemical or crystal bonding, it is almost certain that rapid heating of the mixture would cause fragmentation or exploding at temperatures slightly above 100°C. For this reason, manufacturers of brick must dry their ware of mechanically held water before firing in a kiln to prevent shattering of the ware by exploding steam, but after certain clays or shales are dried, they may be expanded or bloated to a light-weight, cellular material (like the Haydite of industry). The clay mineral in shales which bloat readily is commonly illite, which contains also monomeric and polymeric OH (Keller and Pickett, 1950).

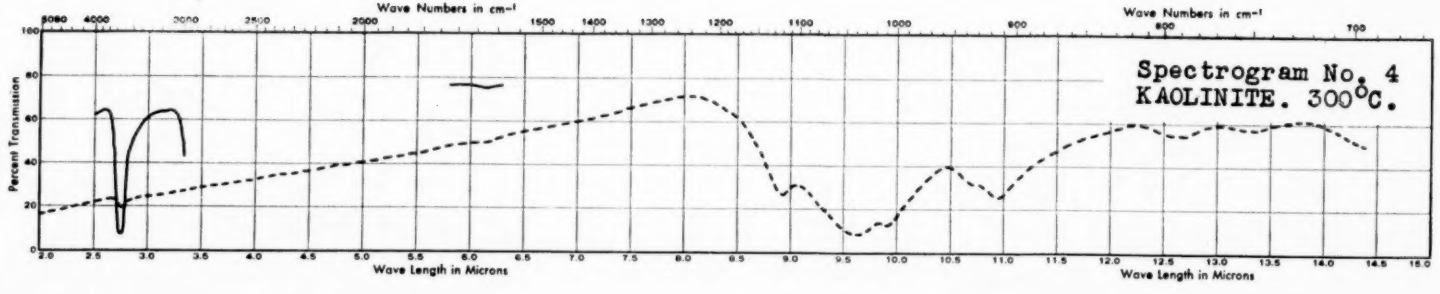
For the reasons discussed above, it is inferred that perlite contains molecular water which is probably completely hydrogen-bonded, and an approximately equal quantity of OH groups which are largely hydrogen-bonded. The structural relationships of this water and OH to the silica-alumina tetrahedra in the glass will be discussed later.

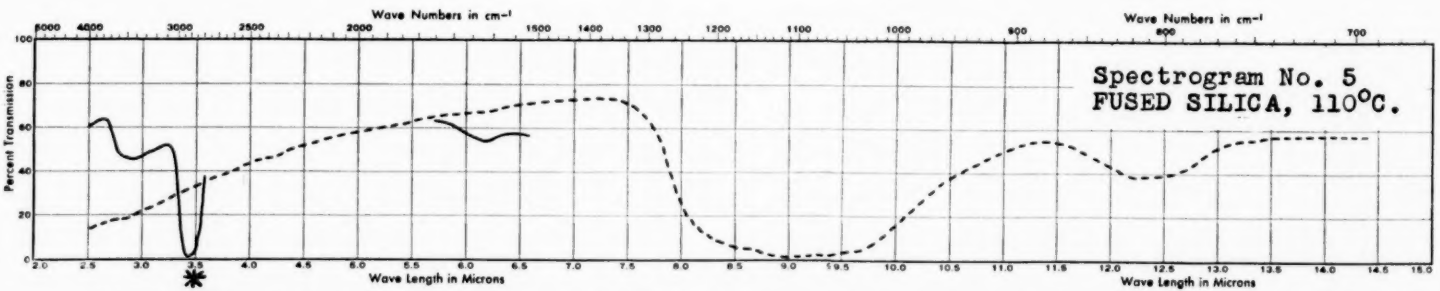
The perlite heated to 350°C.—Spectrogram no. 2 was taken of the Superior perlite heated to 350°C. In comparison with spectrogram no. 1, no. 2 shows much the same absorption over the entire 2-15 micron band, but notably less water in the 2.8 and 6.1 micron regions. Molecular water (band at 6.1 microns) has been almost entirely driven off. The OH groups have likewise been driven off in large quantity, but the ratio of OH groups to molecular water has increased many fold over that in the unheated perlite. The OH groups remaining at 350°C. are more tenaciously held (King, Todd, and Kelley); indeed, if they were not so held, perlite would not exhibit its "popping" characteristic.

A differential thermal analysis curve of the perlite does not show any sharp inflection. Kauffman and Dilling (1950), who also studied by differ-

[3] Personal letter, February 8, 1952.


Spectrogram No. 1
RAW PERLITE. 110°C.
Spectrogram No. 2
PERLITE, 350°C.
Spectrogram No. 3
PERLITE, 1100°C.
Wave Numbers in cm⁻¹
Wave Length in Microns
Percent Transmission





Infrared spectrographs showing percent transmission of radiation on the ordinate and wave lengths in microns plotted on the abscissa. Dashed lines show the spectra of dry powder films, and solid lines are spectra of a heavy suspension of the powder in Nujol. Asterisks indicate absorption due to Nujol.

Spectrogram no. 1 was taken on Superior, Arizona perlite dried at 100°C.; spectrogram no. 2 is of the perlite heated to 350°C.; spectrogram no. 3 is of the perlite which has expanded ("popped") by heating to about 1150°C.

Spectrogram no. 4 is taken from Georgia (Dry Branch) kaolinite dried at 350°C., and no. 5 is of fused silica, pulverized and redried at 100°C.

ential thermal analysis two perlites from Oregon, and two obsidians from New Mexico and Oregon, found no significant D. T. A. peaks in any of these rocks.

The perlite heated to ca 1150°C.—Spectrogram no. 3 was taken of the Superior perlite heated to about 1150°C. The broad absorption characteristic of silica remains; indeed, the spectrogram is closely similar to one of fused silica, no. 5. Only a slight amount of water is shown by absorption between 2.7 and 3.0 microns, and at 6.2 microns in the perlite. The fused silica shows more pronounced absorption by water than does perlite, but this difference is probably due to a high absorption of water by pure silica powder.

The glasses studied by Miss Harrison (1947), including fused silica, showed by infrared absorption that they contained water, and only by special processing was she able to purge a glass melt of water. We conclude therefore, that a glass which has been "ignited," indeed fused, to constant weight in the usual procedure of quantitative analysis may not be entirely devoid of water.

Summary of infrared absorption data—The absorption of infrared radiation by perlite indicates the presence of significant monomeric OH and dominant hydrogen-bonded OH and H_2O. The presence of significant amounts of mechanically trapped H_2O is contraindicated because the perlite does not explode with fragmentation of solid particles, and because it fuses, while containing water, at a comparatively low temperature with the development of rounded bubbles, but assumes a higher temperature of fusion after being dehydrated.

THE STRUCTURAL LOCATIONS OF WATER IN VOLCANIC GLASS

Volcanic glass is similar to artificially prepared glass in structure. Some inference can be made as to the probable structural location of water in a volcanic glass by applying the preceding information obtained from infrared absorption to the structure of artificial glass. Volcanic glasses most probably do not differ significantly in structure from artificially prepared silicate glasses—they differ probably only in containing more Al, Mg, Fe, K and H than does most window glass (soda-lime glass), which is kept "purer" in the manufacturing process. We can, therefore, utilize in the interpretation of the structure of volcanic glasses the rich store of information about artificially prepared glass which has been contributed by Zachariasen (1932), Morey (1938), and Warren and co-workers (of special interest to this report, Warren, 1934; Warren and Loring, 1935; Warren and Biscoe, 1938).

These investigators have shown that silicate glass consists of silica tetrahedra linked at the corners to form a 3-dimensional network. The bonds are of uneven length and strength, which results in the structure's having so low a degree of organization or periodicity as to be non-crystalline. Warren and Loring (1935) summarize the structure of an artificially prepared soda-silica glass as follows:

"A random network picture of the glass is developed, and upon the basis of X-ray intensity curves can be calculated in good agreement with the experimental curves. Each silicon is tetrahedrally surrounded by four oxygens. Part of the oxygens are shared between two silicons; the others are bonded to only one silicon. The double-bonded oxygens build up a continuous silicon-

oxygen framework. The sodium atoms are located at random in the various holes in this framework. There is no evidence for the existence of compounds in the range of composition studied. . . . In vitreous SiO_2, it was found that each silicon is tetrahedrally surrounded by four oxygens at a distance of 1.60A. . . . . " The oxygens bonded to only one silicon were designated as being associated with sodium atoms.

With the above structural picture of glass used as a model, we may develop thereon the structure of the Superior perlite.

A structural model of the Superior perlite—The Superior perlite solidified upon the chilling of a siliceous magma whose composition in major constituents is given by the analysis in table 1. Minor elements and other fugitive constituents probably also present are not recorded, but the architecture of the glass may be inferred in a general way after recalculating the major composition into ratios of atoms. The two righthand columns of table 1 express the atomic composition in terms of a rock cell containing 160 oxygens (Barth, 1948).

The Si and Al, a total of 74.6 atoms, are assigned to tetrahedral coordination with oxygen, requiring 149.2 oxygens. While the magma was at a high temperature prior to quick chilling, Al is most likely to be coordinated tetrahedrally, whereby those 12.1 Al atoms leave a deficit of 12.1 positive valence charges. To supply these charges, they are taken from 14.8, the sum of the positive charges of the Fe^{+++}, Ca^{++}, Na^{+}, and K^{+} cations, leaving 2.8 positive charges.

Presumably the coordinated Al atoms are distributed at random (in about a 1:5 ratio) among the coordinated Si (Zachariassen, 1932). The charge-balancing Fe, Ca, Na, and K atoms (ions) are assumed to be located in holes in the O-Si, Al-O network near the Al positions.

The remaining cations (2.7 cationic charges) will require 2.7 oxygens and will substitute O-M-O bonds statistically for 2.7 oxygen O-Si,Al-O bridges between Si-Al tetrahedra. The O-M-O bonds are relatively weaker than O-Si,Al-O bridges and make the fused perlite more fluid than would be a pure SiO_2 melt. Moreover, the large K atoms (ions) with weak bonds spread over a large coordination, and the smaller Fe, Ca, and Na atoms scattered through the O-Si,Al-O framework tend to weaken it, also contributing to the fluidity of the anhydrous perlite glass at high temperature.

There remain 19 hydrogens and 8.1 oxygens. The most probable location of the hydrogens with respect to the O-Si,Al-O framework must be inferred from the infrared data. The fact that 18 of H, and 8.1 of O do not accord stoichiometrically with H_2O, OH, or some other hydrogen-oxygen compound is of no moment for the following reasons. A chemical analysis which is reported in terms of oxides, as in this perlite and other conventional rock analyses, gives at the most only a ratio of the cations present in the rock. The analysis does not necessarily indicate how many oxygens were present in the original substance[4].

[4] For example, if a "rock" composed of $KMnO_4$ were analyzed and reported in conventional form for rock analyses it would appear as follows:

Before attempting to assign the hydrogens to positions in the perlite structure, let us consider the effects of H on the O-Si,Al-O framework when it is attached in the several possibilities. It will be recalled from the infrared absorption work that both monomeric OH and hydrogen-bonded water were found in the perlite. First, if all of the hydrogens are attached monomerically to oxygens as OH's in the framework, they will *break* 9.5 tetrahedral links, as shown in figure 1.

This is a break which weakens a structure far more drastically than an O-M-O bond which occurs where a metallic cation intervenes. If all of the H did reside as OH, it would mean that the perlite framework of 75 links would have 2.7 weak, and 9.5 broken links—a very weak structure indeed.

Upon heating to a sufficiently high temperature, say 600° to 900°, the OH's begin to form the steam above its critical temperature—in the ratio, $2\ OH^- \rightarrow H_2O + O^{--}$. The glass structure (O-Si,Al-O framework) is weakened even more during the short interval while H_2O forms, vaporizes, and expands. During this momentary interval of interatomic disruption the perlite vesiculates ("pops"). The heat energy which was put into the system by raising the temperature suddenly breaks the OH bonds, a rapid, high-intensity transfer of much energy. Some 124,800 B.T.U. are required per ton to effect the expansion besides the heat required to raise the temperature of rock and expelled steam (King, Todd, and Kelley, 1948).

After the 2 OH's are converted into H_2O and O^{--}, the latter O^{--} connects as a strong bridge the formerly separated Si (or Si,Al) tetrahedra, thereby increasing the viscosity of the expanded glass and raising its temperature of liquefaction several hundred degrees C. This expectation is in accord with the observed changes.

Infrared spectra have shown that only part of the OH is monomeric. Much of it is hydrogen-bonded in the form shown diagrammatically in figure 2 (a), and some as hydrogen-bonded water as in figure 2 (b). Although the details of the structure in (a) are different (by a resonating bond) from monomeric OH, the net result or effect on the expansion of perlite is the same.

Perhaps a third to a half of the water (estimated semiquantitatively from the infrared absorption at 6.1 microns) in the perlite occurs as in (b). This fraction does not weaken the bonds between tetrahedra as drastically as do monomeric OH or that bonded as in (a), but it appears, from the infrared curves, to be evolved along with the other water. Presumably it contributes simultaneously to the expansion of the perlite as the hydroxyl-derived water is driven off.

	wt. percent	mol. percent	cations	oxygens
MnO	60.1	.847	.847	.847
K_2O	39.9	.4235	.847	.4235
	100.00			1.2705

The ratio in the above analysis is K:Mn:O = 1:1:1.5. The true ratio in the compound $KMnO_4$ is obviously 1:1:4. The ratio of K:Mn is correctly 1:1 in both presentations, which accords with the prior statement that rock analyses reported in terms of oxides and performed in the air, i. e. where elements were not determined specifically, give intrinsically only ratios of cations. The report of 19 hydrogens in association with 62.5 silicons, etc., in the perlite is significant, but the 160 oxygens serve only as a convenient basis for standardizing and comparing analyses.

Summary of inferred structure of the Superior perlite.—The Superior perlite is pictured as consisting of a 3-dimensional network of Si and Al tetrahedra which are connected by oxygen bridges. Cations, such as K, Na, Ca, and perhaps Fe, are located in holes within the framework and supply deficit charges for Al which is vicarious with respect to Si, and also link infrequently (because of their small number) Si,Al tetrahedra. Hydrogen occurs as monomeric OH, and in hydrogen-bonded water, both of which give

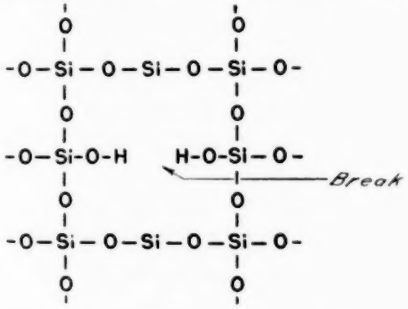


Fig. 1. Diagrammatic representation of monomeric OH attached to two nearby silica tetrahedra. No direct bond exists between the two OH's; the glass framework is discontinuous at this place.

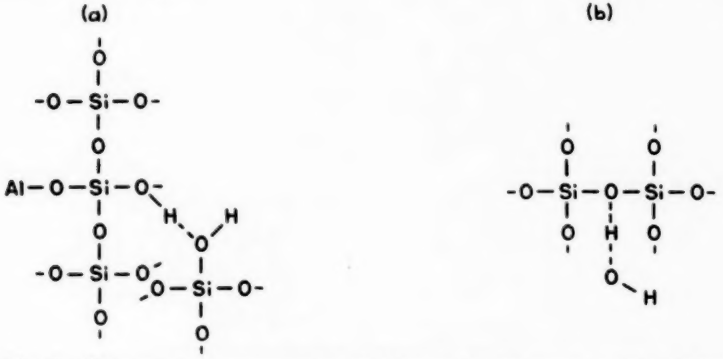


Fig. 2. Diagrammatic representation of hydrogen-bonded water in (a) and hydrogen-bonded OH in (b).

rise to discontinuities and weak spots within the perlite structure. When the perlite is heated to the temperature of expansion or "popping," water (steam) above the critical temperature is formed from the OH, and the perlite is momentarily fused while the chemical bonds are transferred from OH pairs to H_2O and an O^{--} bridge between tetrahedra. This newly formed oxygen bridge increases the viscosity of the dehydrated pumiceous glass and raises its temperature of fusion. The loss of water is presumably irreversible at atmospheric pressure.

Perhaps the structure of the perlite closely represents the structure within the magma at the time of rapid chilling—like a still picture printed from a

single frame of a movie sequence corresponding to the magmatic history of the perlite flow.

ACKNOWLEDGMENTS

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DEPARTMENT OF GEOLOGY
SPECTROGRAPHIC LABORATORIES
UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI

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DISTRIBUTION CURVES FOR LOESS*

ROY W. SIMONSON AND CURTIS E. HUTTON

ABSTRACT. Loess distribution was studied in southwestern Iowa and northern Missouri by measuring maximum thickness at a number of points along two traverses which begin at or near the bluffs beside the flood plain of the Missouri River. The greatest measured thickness of Wisconsin loess is 1380 inches near Council Bluffs, Iowa. The loess thins to the southeast according to an exponential function, and the maximum thickness gradually drops off to as little as 50 inches on an uneroded divide in Boone County, Missouri. The slope of the curve showing loess thickness decreases with increasing distance from the source. The data obtained indicate that the equations already developed for loess distribution curves are valid within restricted geographic ranges but not over the full distance of loess deposition from a single source. The distribution pattern of the loess also suggests the need for further study of silty surface mantles in areas where loess has not been identified in the past.

The nature and distribution of loess formations in the Mississippi Valley, exclusive of the Missouri Valley, have been discussed recently by Leighton and Willman (1950), who cite curves for loess distribution in Illinois. The principal systematic measurements of loess thickness over sizable areas have been made in the Mississippi Valley, especially in Illinois (Smith, 1942). Systematic measurements have also been made in Kentucky, Tennessee and Mississippi (Wascher, Humbert and Cady, 1947), although no effort was made to develop curves for loess distribution patterns in those states. The curves and equations worked out by Krumbein (1937) and Smith (1942) were both based on data obtained in Illinois where possible traverses from single loess sources have maximum lengths of less than 100 miles. Traverses can be extended for approximately 3 times that distance across southwestern Iowa and northern Missouri without encountering important secondary loess sources. This permits the testing of equations for loess distribution curves over greater distances.

NATURE AND SCOPE OF INVESTIGATIONS

The observations of loess distribution in southwestern Iowa were part of an effort to improve the classification of soils for the soil survey of Taylor County (Scholtes, Smith and Riecken, in press). Earlier studies (Kay and Graham, 1943) had shown that the loess in Iowa was not uniform in thickness or composition. Moreover, studies by Bray (1937) and Smith (1942) had demonstrated that the nature of soils could be related to loess distribution patterns in Illinois. Consequently, it was believed that study of the distribution pattern of Wisconsin (Peorian) loess in southwestern Iowa, when coupled with investigations of soil morphology and composition, would improve the understanding and classification of the soils. Inasmuch as the data obtained in studies of soil morphology and composition in southwestern Iowa have been reported elsewhere by Hutton (1950) and Ulrich (1950), they will not be repeated here.

It now seems clear that the Peorian formation, as generally identified in the past, consists of more than one sheet of loess, as was suggested by Leigh-

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ton and Willman (1950). Ruhe (1952) has concluded that a major twofold division of Wisconsin drift and its loess equivalents exists in western Iowa. Mickelson (1950) has interpreted an exposure in western Iowa as indicating the presence of a post-Loveland pre-Iowan loess which might correlate with the Farmdale loess of Illinois. In the loess depth measurements reported in this paper, it was not possible to detect consistent breaks in the sections of loess above the Loveland formation. Moreover, the loess above the Loveland formation seems to have originated from the flood plain of the Missouri River along the western edge of the state.

Evidence for the Missouri River flood plain as the principal source of loess in southwestern Iowa and north-central Missouri seems overwhelming. The thickest deposits of loess, or the highest bluffs, lie immediately southeast of the widest segments of the flood plain. Where the flood plain becomes narrow the adjacent loess deposits are much thinner. Over much of western Iowa the loess was apparently laid down upon a dissected land surface, and the deposits are thickest on the southeast sides of the ridges. These are the lee sides to winds blowing from the northwest. The loess mantle is often deep on the southwest slope and very shallow or absent on the comparable northwest slope of a single ridge. With increasing distance to the southeast the loess becomes thinner according to an exponential function as was found earlier by Smith (1942) in Illinois. On the other hand, the thickness of loess in south-central Iowa is essentially constant along a line running from northeast to southwest or perpendicular to the direction chosen for the two traverses. The distribution pattern of loess in southwestern Iowa, together with changes in the nature of that loess with increasing distance from the Missouri River, is the basis for the conclusion that the Wisconsin (Peorian) loess was blown almost entirely from the flood plain of the Missouri River and that the sediments were carried mainly to the southeast. This is in accord with observations in Illinois (Smith, 1942), other observations in Iowa (Hunter, 1950; Simonson, Riecken, and Smith, 1952, p. 13-20, 58-60, 84), and studies of the lower Mississippi Valley (Wascher, Humbert and Cady, 1947). This interpretation forms the basis for laying out traverses in a southeasterly direction from the Missouri River.

Measurements were made along two traverses extending southeast from the flood plain of the Missouri River which forms the western boundary of Iowa. Traverse no. 1 begins 10 miles from the bluff in Monona County and runs southeast to the Iowa-Missouri state line in southwestern Wayne County. No reliable measurements of maximum loess depths were possible nearer the bluff in Monona County. Traverse no. 2 begins at the bluff in the northern edge of Council Bluffs and runs southeast into Ringgold County. Locations of the two traverses are shown in figure 1. Traverse no. 1 extended for a distance of approximately 170 miles and Traverse no. 2 about 90 miles within Iowa. Traverse no. 2 has been extended for a total distance of approximately 260 miles by the addition of measurements at three sites in Missouri.

Measurements of thickness were made by boring with a soil auger and extensions through the Wisconsin (Peorian) loess into the underlying material, three principal kinds of which occur in southwestern Iowa. In most of the

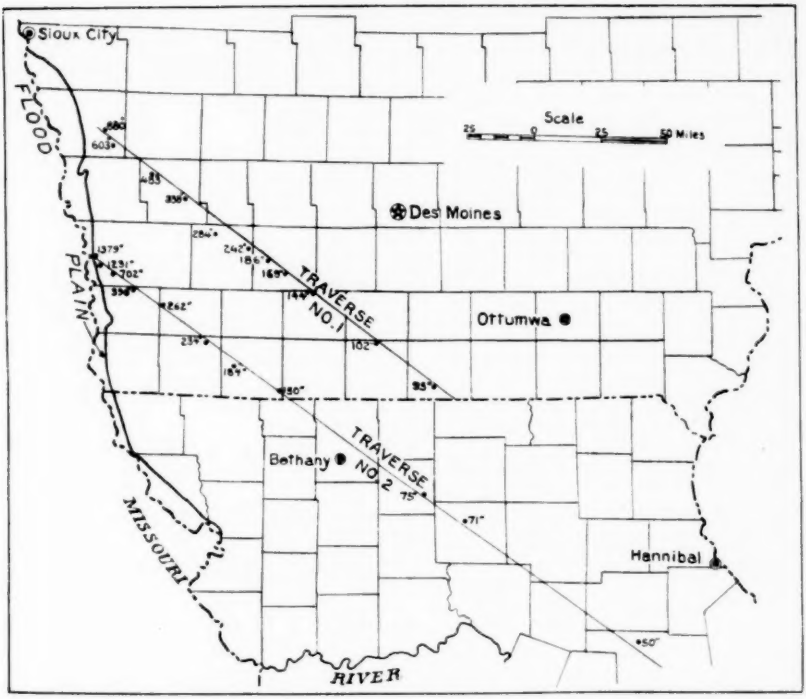

Fig. 1. Map showing approximate locations and loess depths along Traverses no. 1 and 2 in Iowa and Missouri.

area, the loess is underlain by fine-textured glacial till, and the contact between the loess and this till is commonly sharp. On the broad divides in south-central Iowa, the loess is commonly underlain by a soil profile formed from the till (Simonson, 1941), and the contact is seldom as sharp. Apparently, some mixing of the loess and the A horizon of the older soil took place during the early stages of loess deposition. Near the traverse origins, a fine-textured reddish-brown loess (Loveland) underlies the thicker Wisconsin loess in places. Measurements of thickness of Loveland loess were not made because the formation does not occur uniformly and is of limited importance as soil parent material in Iowa.

The actual sites for measurement were chosen to provide data on maximum loess thickness and to space the borings along the traverses. In the hilly to rolling landscapes near the loess bluffs which border the flood plain most of the borings were made in deep road cuts. The loess deposits commonly reach maximum thicknesses of more than 300 inches in a belt ranging from 3 to 30 miles in width east of the Missouri River flood plain. A hand auger does not function effectively to depths much greater than 300 inches, and borings were therefore not feasible on the crests in higher divides unless road cuts were available. In the dominantly hilly to rolling uplands the estimates

of loess thickness are certain to be conservative and may be appreciably low. Some loess has doubtless been removed by erosion during and after the period of deposition. Beyond a distance of approximately 40 miles southeast from the bluff, the uplands include some high-lying tabular divides. These flat upland divides, especially common in south-central Iowa, were chosen as sites for measuring loess thickness. On these divides there has been little opportunity for removal of loess by erosion and it is believed that the measurements of maximum thickness have a high degree of accuracy.

DESCRIBING LOESS THICKNESS

In southwestern Iowa the maximum loess thickness on uneroded sites ranges from as much as 1380 inches near Council Bluffs in Pottawattamie County to 95 inches in Wayne County. The data on loess depths together with the locations at which borings were made are given in table 1. Included in table 1 are three measurements of loess thickness at points in

TABLE 1

Depths of Loess in Southwestern Iowa and Adjacent Missouri

Distance from Source in Miles	Depth of Loess in Inches	Location by Legal Subdivision	Township North	Range West	County	State
		Traverse no. 1				
10.3	680	NW NE NE 16	83	43	Monona	Iowa
20.5	603	SW SE SW 14	82	42	Monona	Iowa
33.0	483	NW NE NE 27	81	40	Shelby	Iowa
55.0	338	NE NE 21	79	37	Shelby	Iowa
65.5	284	NE NW NE 12	77	37	Cass	Iowa
83.5	242	SE SW SE 14	76	34	Cass	Iowa
88.0	186	NW NE 18	75	33	Adair	Iowa
98.5	169	SE SE NE 3	74	32	Adair	Iowa
117.5	144	NW 14	73	30	Union	Iowa
155.0	102	SE SE 8	69	25	Decatur	Iowa
167.5	95	NW NW SE 1	67	23	Wayne	Iowa
		Traverse no. 2				
0.1	1379	SW 11	75	44	Pottawatamie	Iowa
1.6	1231	Council Bluffs	75	44	Pottawatamie	Iowa
6.9	682	SW SE NE 2	74	43	Pottawatamie	Iowa
16.4	390	SW NW NW 4	73	41	Mills	Iowa
30.6	262	NE SE NW 1	71	40	Montgomery	Iowa
46.8	234	SE SE SW 4	70	37	Page	Iowa
66.4	184	Middle 20	68	35	Taylor	Iowa
86.7	150	NW SW SW 33	67	32	Taylor	Iowa
157.0	75	Sec. 26	61	24	Grundy	Mo.**
175.0	71	Sec. 5	57	22	Livingstone	Mo.**
257.0	50	Sec. 10	51	11	Boone	Mo.**

* Legal subdivisions within sections are abbreviated by omission of the figure "¼." For example, a full description would read NW¼ NE¼ NE¼ Sec. 16.

** Personal communication from G. D. Smith and W. D. Shrader.

Missouri which represent an extension of Traverse no. 2. These three sites lie 150 to 260 miles from the point of origin of the traverse. Some question may be raised about the inclusion of the three measurements in Missouri. The

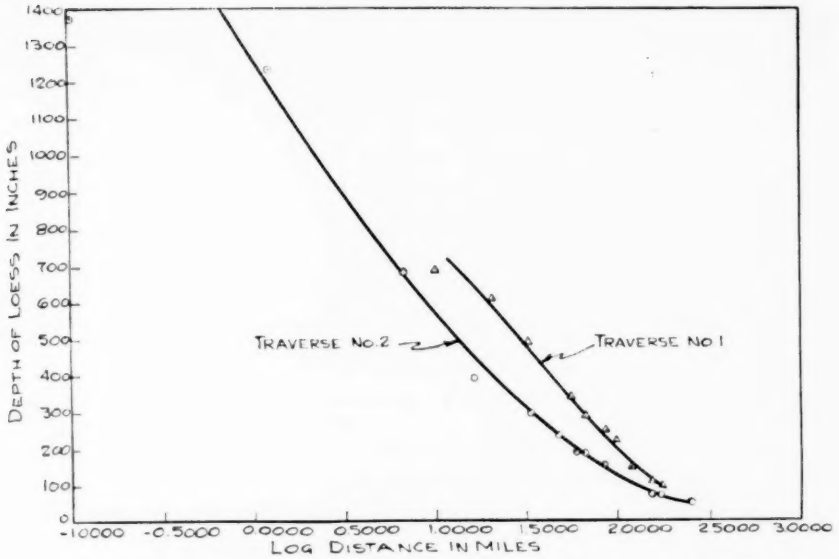

Fig. 2. Graph showing relationship of maximum depth of loess to the logarithm (to base 10) of distance from the source.

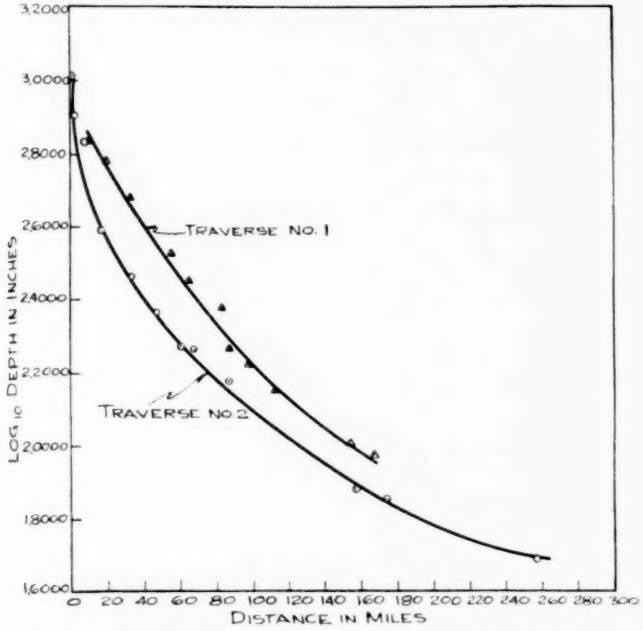

Fig. 3. Graph showing relationship of the logarithm (to base 10) of the maximum depth of loess to the distance from source.

validity of extending the curve on the basis of those measurements cannot be fully tested until more measurements are available. Examinations of loess thicknesses in south-central Iowa and northern Missouri in the course of field trips, however, indicate that maximum loess thickness can be predicted with a high degree of accuracy from the curves along the full extent of Traverses no. 1 and 2. Data for both traverses indicate the gradual thinning of the loess with increasing distance from the Missouri River.

The data given in table 1 are shown graphically in figures 2 and 3. In figure 2, the depth of loess in inches is represented on the "y" axis, and the logarithm to the base 10 of the distance in miles from the bluff is given along the "x" axis. This method for plotting the data follows that of Smith (1942). In figure 3, the logarithm to the base 10 of loess depth in inches is plotted along the "y" axis, whereas the distance in miles from the bluff is plotted on the "x" axis. This follows the method used by Krumbein (1937). The relationships between loess thickness and distance from source, as indicated in figures 2 and 3, are essentially similar to those demonstrated earlier by Krumbein and Smith. The loess becomes thinner with increasing distance from source according to an exponential function. The curve for Traverse no. 2 in figure 2 also shows a discontinuity or break comparable to that observed earlier by Smith (1942). A similar break is not evident in the curve for Traverse no. 1, but the observations nearest the bluff are 10 miles from the edge of the flood plain. A discontinuity in the curve could occur between that point and the bluff itself.

The traverses made in Iowa were longer than those possible in Illinois (Smith, 1942; Krumbein, 1937), and they could be extended into Missouri without danger of encountering important secondary sources of loess. The traverses made by Krumbein (1937) and Smith (1942) have maximum lengths of 13 and 70 miles respectively. Traverse no. 1 was 170 miles long in Iowa, whereas traverse no. 2 was 260 miles long when extended to cover the observations in Missouri. These observations over longer distances indicate that the slope of the loess distribution curve changes as the distance increases.

When the distribution curve for loess is extended beyond points that are 100 miles from the source, the slope begins to change and the curve becomes asymptotic to the "x" axis. This trend is evident in both figures but is more prominent in figure 3. The rate of thinning decreases sharply 170 to 200 miles from the loess source. Thus, the curves in figures 2 and 3 indicate that equations already developed to describe loess distribution are valid within certain geographic limits. They cannot be extended with confidence to cover the entire distance over which loess may be deposited from a given source. Although this study indicates that previous equations are not fully adequate to describe loess distribution, the data obtained do not seem adequate in themselves for the development of new equations. The curves presented in either figure 2 or figure 3 can be used to estimate maximum loess thickness with a high degree of accuracy in southwestern Iowa and north-central Missouri. Moreover, the studies of soils (Hutton, 1950; Ulrich, 1950) have indicated that there is a close relationship between the nature of the soils formed from loess and the maximum thicknesses of the deposits in southwestern and south-central Iowa.

The shape of the distribution curve for loess in south-central Iowa and north-central Missouri is also of interest because it suggests that loess may be deposited in quantity much further from the source than has been commonly supposed. This emphasizes the need for further investigation of silty surface mantles which have not been considered loess in the past. It does not demonstrate that all silty mantles are loess. It does, however, indicate that the study of silty mantles ought to include as one working hypothesis the possible origin of the sediments as loess. For example, occasional areas of Dewey and Etowah soils in Franklin County, Tennessee are far more silty in the upper horizons than is common. The Dewey soils are normally derived from limestone which is relatively low in chert and other impurities, whereas Etowah soils have been formed from alluvial material in stream terraces. The topographical position of the soils in the present landscape would permit them to have been covered by a shallow mantle of loess in the past, but it is hard to imagine conditions which would allow deposition of silty sediments by other means. Yet the area is far removed from important loess sources such as the Mississippi and Ohio Rivers. The fact that loess has been carried great distances across southern Iowa and north-central Missouri suggests re-examination of the thin silty mantles in areas such as south-central Tenessee and northern Alabama. Similar problems may exist in other areas. These surface mantles are of importance to the formation and classification of soils even when they comprise but part of the soil profile. More effective consideration can be given to such mantles when their nature and origin is understood.

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U. S. Department of Agriculture
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Washington, D. C.

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ADDITIONAL POLLEN PROFILES FROM SOUTHEASTERN ALASKA

CALVIN J. HEUSSER

ABSTRACT. Pollen and peat stratigraphy of three additional muskeg sections taken from the mainland of southeastern Alaska, north of the Alexander Archipelago, corroborates results from seventeen sections obtained elsewhere in the "panhandle." Muskegs of this study are located at: (1) Icy Point, (2) Excursion Inlet, and (3) Chilkat Peninsula. This work constitutes a further investigation of the postglacial development of the Coast Forest Formation in the Territory.

Excursion Inlet section contains the oldest record of the three discussed. Pollen sedimentation began with lodgepole pine (*Pinus contorta*) and is estimated to have occurred between 8000 and 6000 years ago (Period I). Succession to Sitka spruce (*Picea sitchensis*) followed between 6000 and 5000 years ago (Period II) and culminated in the development of the regional western hemlock (*Tsuga heterophylla*)-Sitka spruce forest climax (Period III). Climate is presumed to have been cool and moist during early postglacial time (Period I), but subsequently underwent amelioration (Period II), becoming warmer and drier (Period III). Period III lasted until 2000 years ago when climate became cooler and wetter. This late-postglacial interval (Period IV) is associated with the time of renewed glaciation ("little ice age" of the late François Matthes). Period IV is placed between 2000 and 200 years ago. Areal increase of muskeg at the expense of forest is in evidence at this time as indicated by a maximum of lodgepole pine pollen in moss peat overlying buried forest remains. General glacier recession occurred in southeastern Alaska approximately 200 years ago. Warmer and/or drier climate (Period V) is inferred as a result of decreased sedimentation of pine pollen at the surface of the profiles, the invasion of muskeg by trees of the upland forest, and by glacier retreat.

Genesis of muskeg at Icy Point and Chilkat Peninsula is interpreted as occurring during Period IV, that of the former as a consequence of withdrawal of the sea from the site and that of the latter as a result of increased moisture and cooler temperatures.

INTRODUCTION

Further opportunity was afforded during the 1952 summer to sample muskegs in the North Pacific coastal district of North America. The purpose of this work is essentially to reconstruct the postglacial history of the Coast Forest Formation in this region. Climatic change, glacier history, shoreline variation, and chronology are also taken into consideration.

Eight sections were obtained from muskegs located in the northern "panhandle" of southeastern Alaska, near Cordova in Prince William Sound, and near Seward on Kenai Peninsula. The study of sections gathered in 1950 and 1951 has previously been reported (Heusser, 1952). A total of 25 sections has now been taken over a distance of 750 miles, extending from Ketchikan in the southeast to Seward in the northwest. This paper will discuss the palynology of three additional sections from the mainland of southeastern Alaska, north of the Alexander Archipelago (fig. 1): (1) from Icy Point near the terminus of La Perouse Glacier on the open ocean, (2) from Excursion Inlet off Icy Strait and east of Glacier Bay, and (3) from Chilkat Peninsula near Haines. Results of studying sections from Cordova and Seward will be presented elsewhere.

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PHYSIOGRAPHY AND GLACIATION

Three prominent mountain systems separated by two extensive fiords are the conspicuous topographic features of this region (fig. 1). These are aligned northwest-southeast. Fairweather Range is farthest west bordering the Pacific Ocean and is highest of the three. Mount Fairweather (15,300 feet) and Mount Crillon (12,725 feet) are especially notable. Parallel to the Fairweather Range is the Chilkat Range to the east. This mountain mass reaches to over 7000 feet in elevation but lacks the rugged character of the "Fairweathers." The northern Coast Range is farthest east with maximum elevations generally in the neighborhood of 7000 feet. Devils Paw northeast of Juneau is the highest point in the vicinity at 8584 feet.

Waterways of the Glacier Bay fiord network are between the Fairweather and Chilkat Ranges, while Lynn Canal separates the "Chilkats" and the Coast Range. Glacier Bay reaches over 60 miles northwest of Icy Strait. Lynn Canal above Admiralty Island is approximately 50 miles in length and bifurcates at its head into Chilkat and Chilkoot Inlets.

Glaciers and ice fields cover much of the region. Glaciers emanating from the Fairweather Range reach to Glacier Bay on the northeast and to the Pacific Ocean on the southwest. Brady Glacier is the largest, draining into Taylor Bay, an arm of Cross Sound on the southeast. Glaciers of the southern Chilkat Range are smaller and less numerous. Considerable area of the Coast Range is overlain by ice. A continuous névé extends from the Juneau Ice Field, just north of the territorial capital, to Skagway.

During the Wisconsin stage of the Pleistocene, ice covered most if not all of the region. There is no information available that would designate with assurance any ice-free areas during this time. The extent of Wisconsin ice in relation to maxima of previous stages is not known. Estimated time of recession is placed at approximately 8000 years ago (Heusser, 1952). Until further radiocarbon determinations become available, this figure will have to represent the length of post-Wisconsin time.

Glaciers were rejuvenated approximately 2000 years ago following a warmer and drier interval (Heusser, 1953a). A late-postglacial ice maximum or "little ice age" as described by Matthes (1939) resulted. Since the middle

of the 18th century, ice of this maximum has generally been receding, as indicated by the work of Cooper (1937) and of Lawrence (1950).

Marine waters invaded this portion of the continent following Wisconsin ice recession. Subsequently, readjustment brought about regression. A survey of recent shoreline change has been made by Twenhofel (1952). The following is of importance in connection with this study. At Adams Glacier in Glacier Bay, the present land-sea differential is 50 feet, although this must be a net figure since interstadial tree stumps are submerged in the bay a few feet below high tide. No overall figure is given for Haines. There has been

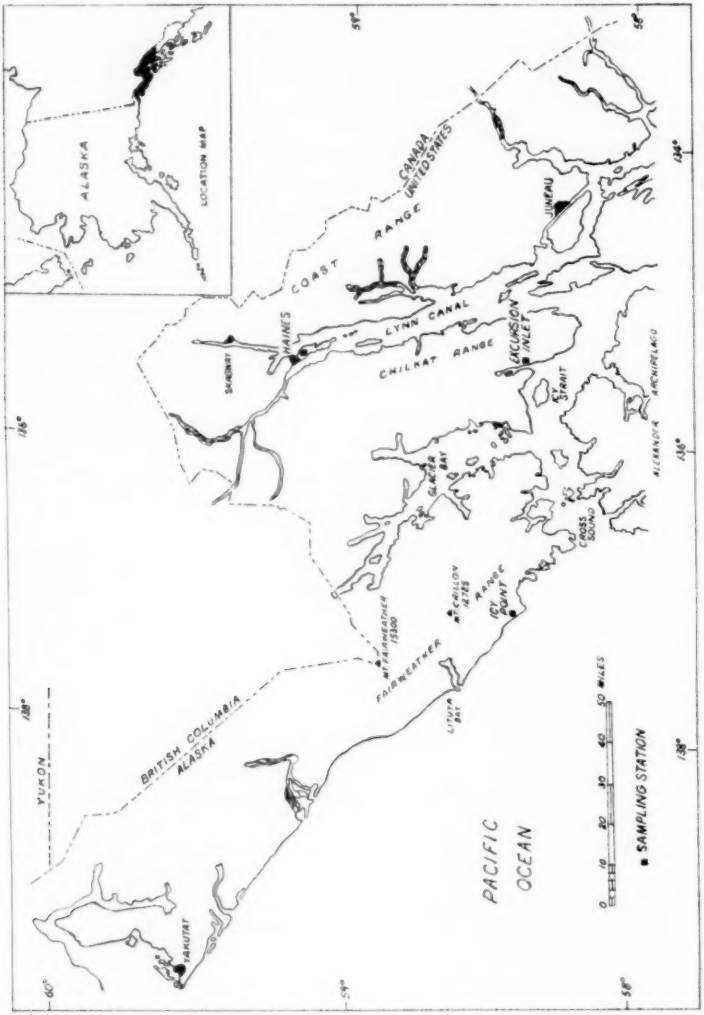

Fig. 1. Sketch map of the portion of southeastern Alaska where study was executed; darkened area of inset map corresponds to the location of study region in the Territory.

recorded, however, a four-foot land rise relative to sea level between 1890 and 1950. Uplift in the Juneau vicinity has been determined at as much as 500 feet. Between Lituya and Yakutat Bays, marine deposits have been elevated to 100 feet since the time of most recent glaciation.

Readjustment in the region of Icy Point and Lituya Bay has produced a series of terraces which have been described by Mertie (1933). The first terrace begins about 3 miles southeast of Lituya Bay and extends 300 to 800 feet from tidewater. The second and third terraces begin about 4 miles southeast of the bay. The second is 200 feet above sea level and 2000 feet from tidewater. The third is approximately 1000 feet above sea level.

CLIMATE

Climate of the North Pacific coastal region is generally mild and moist. Inland along the fiords away from the open ocean, precipitation declines, and the yearly range of temperature is greater. Annual average precipitation at Yakutat is 129 inches, at Juneau 83 inches, and at Haines 56 inches (Kincer, 1941). The locations of these stations are between the ocean and the head of Lynn Canal (fig. 1). No records are available for the study areas of Icy Point and Excursion Inlet. Drier conditions at upper Lynn Canal are reflected by the paucity of muskegs at Haines and the total lack of muskegs at Skagway (Taiya Inlet above Haines; annual average precipitation 27 inches).

January average temperatures for Yakutat, Juneau, and Haines range from 23 to 29°F. while July averages are from 53 to 58°F. Records from Haines show the lowest minimum at −15°F. and the highest maximum at 90°F. The growing season is longest in Juneau with 172 days and shortest at Haines with 122 days.

VEGETATION

Forest and muskeg constitute the major vegetational types of this district. The western hemlock (*Tsuga heterophylla*)-Sitka spruce (*Picea sitchensis*) association of the Coast Forest Formation represents the regional forest climax[1]. Mountain hemlock (*Tsuga mertensiana*) is common from sea level to timberline at approximately 3000 feet. It may be pure or locally mixed with alpine fir (*Abies lasiocarpa*) at this upper limit of tree growth. Alpine fir is present in the Coast Range, but has not been reported from the country west of Lynn Canal (Heusser, 1954). Alaska yellow cedar (*Chamaecyparis nootkatensis*) is conspicuous along the ocean border. Inland it is less frequently found.

Plant succession following deglaciation is initiated on outwash by fireweed (*Epilobium latifolium*) and lupine (*Lupinus nootkatensis*). Seedlings of spruce and mountain hemlock, as well as alder (*Alnus* spp.), willow (*Salix* spp.), and black cottonwood (*Populus trichocarpa*), become established simultaneously. Alder and willow soon form a thicket stage, but are overtopped by cottonwood. Spruce subsequently overtops these deciduous species, shading them out and forming stands with varying amounts of shade-tolerant mountain hemlock. As organic matter accumulates in the spruce forest, western hemlock establishes itself and develops to predominance. The western hemlock-

[1] Nomenclature followed is that of Hultén (1941-1950).

Sitka spruce forest climax is thus developed with an admixture of principally mountain hemlock and Alaska yellow cedar. Various stages of the prisere are evident as a result of general ice recession since the middle of the 18th century.

Muskegs are present as three distinct types: slope, raised, and flat. Flat muskegs occur in broad level valleys and are usually shallow. Raised muskegs are uncommon, whereas slope muskegs are the most commonly encountered of the three types. In the region studied, this latter type occupies gently sloping benches near the ocean. The drier inland margins of fiords exhibit few muskegs. As one travels north from Juneau to Haines, for example, muskegs decrease in abundance. Lower precipitation and lack of suitable terrain for development are the major factors responsible. Muskegs are found throughout the mainland at low elevation north of Cross Sound and Icy Strait. Many of the larger islands such as Pleasant Island are comprised almost entirely of muskeg.

Vegetation presently growing on muskeg is composed for the most part of heaths, sedges, mosses, and lodgepole pine. Heaths are represented by blueberries (*Vaccinium uliginosum; V. vitis-idea*), crowberry (*Empetrum nigrum*), Labrador tea (*Ledum groenlandicum*), laurel (*Kalmia polifolia*), and bog rosemary (*Andromeda polifolia*). Sedges are largely *Scirpus caespitosus* var. *callosus*, *Carex pauciflora*, and *Eriophorum* spp., while, most commonly, mosses are *Sphagnum* spp. Lodgepole pine is well developed on some muskegs and attains sizes of 2 feet d.b.h. (diameter breast high) and 50 feet in height. It is unable to compete with the members of the forest climax and as a consequence is restricted to muskeg. Hemlocks, spruce, and Alaska yellow cedar occur in small numbers in addition to pine.

POSTGLACIAL CHRONOLOGY

Previous studies (Heusser, 1952) have discussed a postglacial chronology for the region. Generalized peat and pollen stratigraphy and vegetational, climatic, and glacial events are summarized and collectively shown in figure 2. The earliest record discloses a lodgepole pine maximum (Period I) which is estimated to have occurred sometime between 8000 and 6000 years ago. This maximum is interpreted as representing an early time of physiographic instability suggesting such conditions attendant to ice retreat as avalanching, flooding, differential uplift, and mud flows. Lodgepole pine was an early invader on such changing terrain because of its ability to withstand adverse conditions. This tree was superseded by Sitka spruce (Period II; 6000 to 5000 years ago) and by western hemlock-Sitka spruce as amelioration took place. Lodgepole diminished during this time as a result of its inability to compete with these trees. This condition characterized the warmer and drier interval (Period III; 5000 to 2000 years ago). Muskeg was invaded by upland forest trees during this period, as indicated by the presence of stumps and logs in the peat and evidence of fire and oxidation. The subsequent gradual increase of lodgepole pine is correlated with the "little ice age" interval (Period IV; 2000 to 200 years ago). Muskeg developed at the expense of the forest on low-lying areas, whereas well-drained slopes which were too steep for muskeg formation retained the forest cover. Sitka spruce diminishes

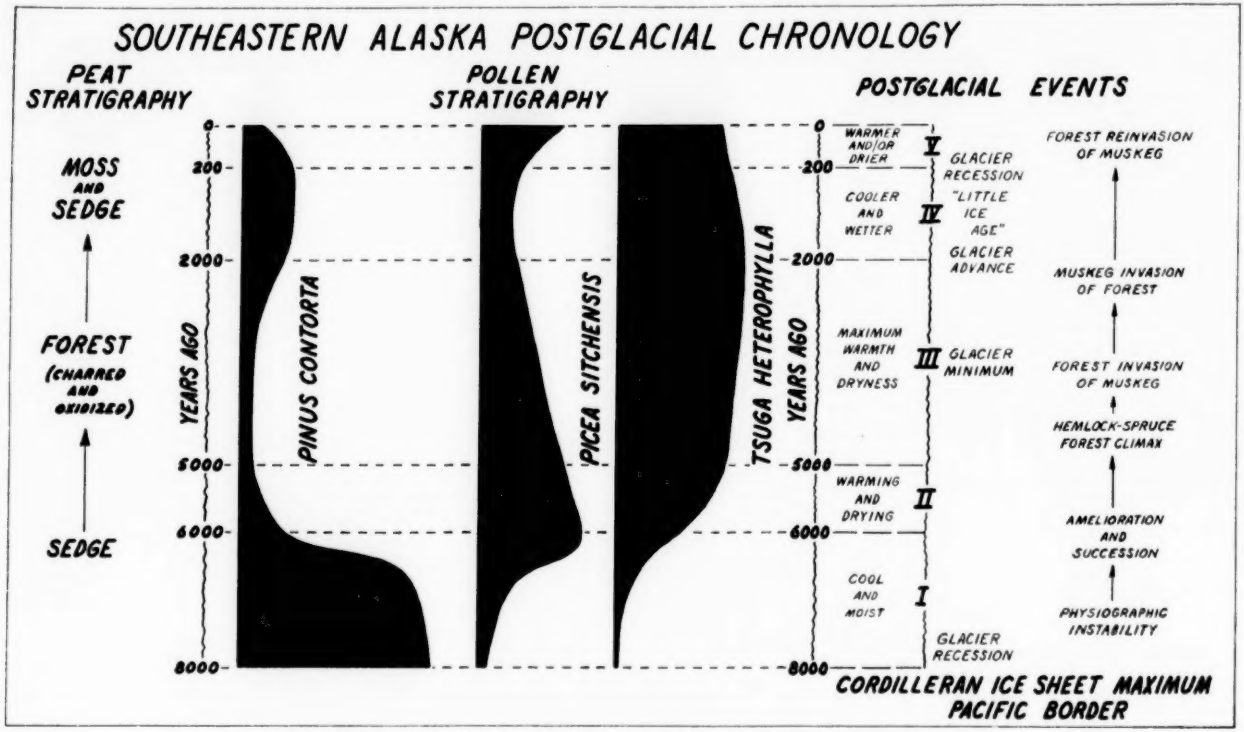

Fig. 2. Southeastern Alaska postglacial chronology showing sequence of events and generalized peat and pollen stratigraphy for regional muskegs.

during Period IV, and western hemlock reaches its greatest predominance. This latter trend is not always evident since the concurrent rise of pine has had a "masking" effect on the hemlock profile. Since the recession of glaciers of the late-postglacial ice maximum Sitka spruce and mountain hemlock have registered an increase in their profiles, thus relating their early role in succession (Period V; 200 years ago to the present). Pine has conversely decreased. Evidence for the present warming and/or drying is supported by this fact and the fact that forest trees are again invading muskeg.

MUSKEG LOCATION AND CHARACTER

Icy Point muskeg was sampled approximately 3 miles southeast of the terminus of La Perouse Glacier on the Pacific Ocean and 200 yards in from the beach (fig. 1). The surface is covered by sedges (*Scirpus caespitosus* var. *callosus; Carex pauciflora*), crowberry, and blueberry (*Vaccinium vitis-idea*). Skunk cabbage (*Lysichitum americanum*) and deer cabbage (*Fauria crista-galli*) are present in depressions. Lodgepole pine is the most common tree, although Sitka spruce, Alaska yellow cedar, and both hemlocks are found. Lodgepole attains sizes over 1 foot d.b.h. and 50 feet tall. Here it is near the end of its range. This station appears to be the highest latitudinal locality on the coast. Hultén (1941-1950) does not indicate it north of Dixon Harbor (12 miles southeast) and Brink (Cooper, 1939) does not list it for the vicinity of Crillon Lake (12 miles northwest).

Vegetation just above the beach is largely beach grass (*Elymus arenarius* ssp. *mollis*). Beach pea (*Lathyrus maritimus*) and strawberry (*Fragaria chiloensis*) are also in evidence. Trees of the beach fringe are young Sitka spruces with an understory of devil's club (*Oplopanax horridus*) and blueberry (*Vaccinium alaskaensis*). At the edge of the muskeg specimens of cedar are found 1 foot d.b.h. and 50 to 60 feet high. These are much smaller, however, than those observed at Lituya Bay by Mertie (1933). This locality is 21 miles northwest up the coast. The trees were measured with a d.b.h. of as much as 8 feet, and those 5 feet d.b.h. were as much as 140 feet tall.

Peat in the muskeg was sectioned to a depth of 1.4 meters. It consists of surface moss with underlying sedge. Some woody fragments were collected in the sedge peat, and numerous logs are buried in the sediments. Sampling was carried out with difficulty because of this. Dark beach sand was encountered at 0.8 dm. mixed with sedge remains. Sand lacking organic matter forms the base of the section.

The deepest muskeg sampled is located at Excursion Inlet (fig. 1). It is 2.5 miles south of Tongass Lodge at approximately 200 feet above sea level and at a low angle of slope. Muskegs occupy considerable area along the southern edge of the Chilkat Range. Excursion Inlet muskeg is one of the nearest to Glacier Bay where recession of ice amounting to over 60 miles has occurred since the middle of the 18th century (Cooper, 1937).

Labrador tea, crowberry, and cloudberry (*Rubus chamaemorus*) are the important low level plants on the muskeg. Lodgepole pine is common, with some individuals 1 foot d.b.h. and 50 feet in height. Western hemlock and Sitka spruce are sparsely represented. Sphagnum is thick and spongy at the surface.

The section obtained is 3.5 meters. A mixture of sedge and moss forms much of the column. Wood peat and considerable decomposition are evident between 2.4 and 2.5 meters and underlain by sedge peat. Samples collected in the upper meter were generally soupy, and so much so that at 0.6 meter none could be secured in the chamber of the Hiller borer. The base of the organic sediments rests on sandy clay containing pebbles.

The muskeg studied on Chilkat Peninsula near Haines is one of the few in this vicinity. It was located after an aerial survey of the peninsula and is situated to the west of the Civil Aeronautics Administration radio station south of the town. The surface slopes gently to the northwest, and at the time of sampling (early August) pockets in the peat and clumps of sphagnum had dried markedly. Blueberry (*Vaccinium uliginosum*) and Labrador tea are prevalent, with sedge (*Carex pauciflora*), crowberry, and cranberry (*Oxycoccus microcarpus*) noticeably present. Lodgepole pine is the most common tree. It is generally low in stature, although some trees attain heights of 50 feet and a 1 foot d.b.h. Larger trees occur along the margin of the muskeg. Western hemlock and Sitka spruce are sparse on the muskeg surface. The regional forest is composed of a greater profusion of deciduous trees in comparison to the islands and bordering mainland of the Alexander Archipelago to the south. These include alders, poplars (*Populus tacamahacca; P. trichocarpa*), maple (*Acer glabrum* var. *douglasii*), and crabapple (*Malus fusca*).

The peat section from this muskeg is the shallowest of the three studied. It is 0.7 meter in depth and rests on silty sand. The surface sediments are moss remains, while lower organics are of sedge with some woody material.

It may be of interest to mention that structures described by Godwin and Andrew (1951) as resembling ascomata of *Microthyrium* were observed at several horizons in the Excursion Inlet section. No volcanic ash was noted in any of the samples from these three muskegs.

METHODS

It was possible with the aid of a light airplane (PA-12 Super Piper Cruiser) based in Juneau to obtain sections from places that otherwise would have been difficult to reach. Furthermore, it was an effective way to survey muskeg and to choose locations that appeared to be most profitable. Landing sites were the beach at Icy Point, the tide flat at Dundas Bay, the road at Excursion Inlet, and the strip at Haines.

Sediments in stratigraphic section were taken by use of a Hiller borer. Shafts used with the Hiller head were made of aluminum alloy tubing and are similar to those designed by Lichtwardt (1952). Sampling was conducted through the peat into the underlying inorganics. Samples were removed from the chamber with care in order to avoid contamination and were placed in 8-dram shell vials and corked. After returning from the field, alcohol preservative was added to each sample.

Laboratory treatment involved boiling the samples for a few minutes in dilute KOH to which several drops of aqueous methyl violet had been added. Deflocculated material was poured through a wire strainer, and the strained

TABLE 1

Analysis of Icy Point Muskeg, Alaska

Depth in decimeters	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
Pinus contorta*	14	16	8	7	3	4	3	1	0	0	3				0
Picea sitchensis*	38	36	34	31	29	34	46	49	51	65	52				71
Tsuga heterophylla*	41	43	52	52	57	56	46	46	42	27	45				28
Tsuga mertensiana*	7	5	6	10	12	6	4	3	7	7	0				1
Unknown**	2	5	5	7	7	6	3	3	25	26	11				11
Polypod	11	7	8	11	7	6	560	77	62	140	90				48
Lycopod	2	5	18	49	22	11	2	3	7	—	1	NO GRAINS	NO GRAINS	NO GRAINS	—
Selaginella	—	—	2	2	2	—	2	—	—	—	—				—
Cyperad	15	51	39	56	20	7	7	6	4	8	2				—
Lysichitum	1	6	8	35	21	29	47	27	51	30	24				1
Salix	—	1	—	—	—	—	—	—	—	—	1				—
Alnus	13	16	57	55	24	92	250	21	28	22	12				—
Betula	—	—	2	—	—	—	—	—	—	—	—				—
Ericad-Empetrad	—	3	4	7	4	3	11	2	5	2	4				1
Plantago	—	—	10	18	6	10	11	1	4	8	2				—
Cornus	1	—	—	—	—	—	1	—	—	—	—				—
Compositae	2	—	—	—	—	—	—	—	—	—	—				—

*Percent of total count.

**Unknown conifers included in total count.

liquid containing the pollens and spores was centrifuged. Sediments thus obtained were mixed with a few milliliters of clear glycerine gelatin mixture. A few drops of this material were then placed on a clean microscope slide and mounted under a 7/8-inch square cover glass. Examination of each sample was made at magnifications of 100x and 440x under a calibrated binocular compound microscope equipped with a mechanical stage.

A total of 150 grains of lodgepole pine, Sitka spruce, western hemlock, and mountain hemlock, including unknowns of these, was counted. The percentage of each coniferous species was calculated, based on the total identified conifer grains counted. Numbers of other entities were tabulated during the count. *Salix* and *Artemisia* were separated on the basis of reference material and the recent paper by Straka (1952).

RESULTS

Palynology of the muskegs is found in tables 1, 2, and 3 and that for the major coniferous trees is shown diagrammatically in figure 3. The oldest record of vegetation (Period I) is in the Excursion Inlet profiles. Lodgepole pine contributes 99 percent of the basal arboreal pollens (3.1 meters). *Selaginella* microspores are abundant at the bottom of the section, and polypodiaceous fern spores are numerous at this level as well as at levels to 2.4 meters (table 2).

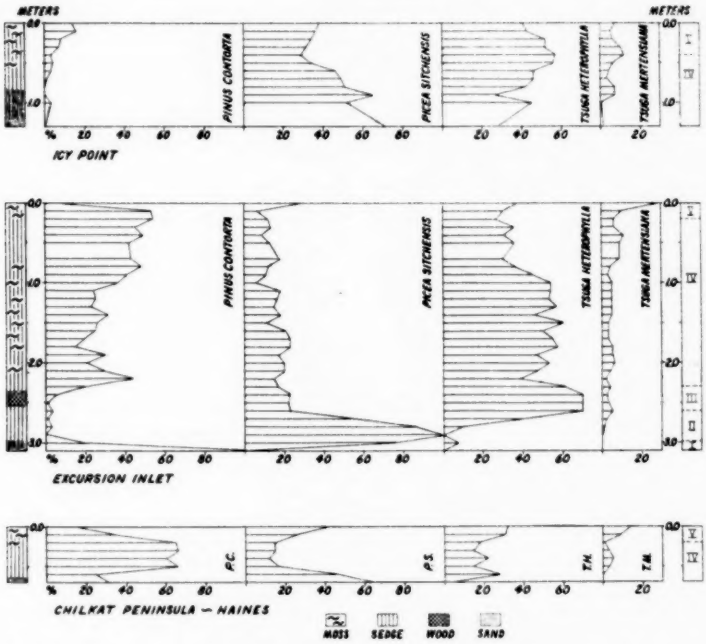

Fig. 3. Peat sections, pollen profiles, and environmental sequences for muskegs at Icy Point, Excursion Inlet, and Chilkat Peninsula, southeastern Alaska.

TABLE 2

Analysis of Excursion Inlet Muskeg, Alaska

Depth in decimeters	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1
Pinus contorta*	7	53	54	45	49	42		43	48	41	36	24	25	23	31	26	25	19	15	30	21	29	44	19	5	1	3	1	3	0	18	99
Picea sitchensis*	27	7	12	13	9	13		18	12	11	6	18	16	15	18	11	21	23	23	17	20	20	15	17	23	22	23	55	86	100	75	1
Tsuga heterophylla*	37	30	27	36	31	36		30	36	45	54	54	53	57	46	60	50	55	57	47	53	47	39	61	70	70	70	43	10	0	7	0
Tsuga mertensiana ..	29	10	6	6	11	9		9	4	3	5	5	5	5	5	3	3	3	5	5	6	3	2	4	2	3	5	2	1	0	0	0
Unknown**	10	7	7	7	4	11		10	5	4	7	2	3	—	3	2	—	—	—	—	4	2	—	—	—	—	—	—	1	—	13	5
Polypod	—	1	—	3	4	5		1	3	—	2	2	2	6	8	5	11	5	4	8	6	9	5	13	59	144	130	896	744	550	3250	1807
Equisetum	—	—	—	2	—	1		1	2	—	—	—	—	—	1	—	—	—	1	—	—	—	—	3	2	3	—	—	—	—	—	—
Lycopod	—	1	—	—	—	2		—	1	—	1	—	—	—	—	1	1	—	1	—	—	—	1	20	23	8	2	1	—	—	2	4
Selaginella	—	—	—	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	74
Cyperad	4	3	5	6	6	6		10	13	5	8	1	3	5	3	4	—	3	3	4	—	9	1	7	13	53	110	22	14	4	6	—
Lysichitum	—	—	—	—	—	—		3	8	4	3	—	1	7	2	—	1	5	—	—	5	5	6	1	4	5	6	12	2	1	—	2
Alnus	3	—	2	5	3	6		10	18	8	21	5	5	17	4	7	6	7	4	4	4	11	29	10	12	27	18	46	39	26	12	1
Betula	1	—	—	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ericad-Empetrad	6	1	1	4	1	1		—	2	—	1	—	5	2	3	3	2	1	59	25	36	—	—	2	2	1	4	15	2	1	—	1
Rubus	—	—	—	—	—	—		—	3	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Cornus	—	—	—	—	1	—		1	2	—	—	1	1	—	1	—	1	—	1	—	—	1	—	2	2	17	8	3	—	—	—	—
Artemisia	—	—	—	—	—	—		—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—

NO SAMPLE

*Percent of total count.

**Unknown conifers included in total count

Lodgepole predominance (Period I) is superseded by Sitka spruce. Spruce attains a maximum and predominates over pine and the two hemlocks (Period II). Subsequently, western hemlock reaches its maximum and initiates its association with spruce (Period III). Lodgepole is low at this time but increases during later sedimentation to a maximum at the close of Period IV. A lodgepole peak also occurs at 2.2 meters. Spruce and western hemlock show a general decrease during Period IV. Spruce and mountain hemlock rise sharply in the surface sediments, while pine rapidly falls off.

Periods IV and V are expressed in the profiles for the Icy Point section (fig. 3). Lodgepole gradually rises from the bottom to the top of the profile and is poorly represented in comparison to the Excursion Inlet pine profile. Spruce and western hemlock are, on the other hand, present in large numbers. Spruce pollen shows a greater density in the peat of Period IV than in that for Excursion Inlet. During Period V there is an increase of spruce and a decrease of western hemlock with no indicative trend in mountain hemlock. *Plantago* is present throughout most of the sediments. Polypods, lycopods, cyperads, *Lysichitum*, and *Alnus* are likewise found in most if not all of the levels studied and are more abundant than other non-arboreal pollens.

Chilkat Peninsula (Haines) profiles in figure 3 are also coincident with Periods IV and V. Pine rises to predominance above the bottom of the profile with a decline to the surface. Spruce behaves conversely in declining above its basal predominance, but rising in the upper levels. Western and mountain hemlock pollen generally increases to maxima at the surface.

TABLE 3

Analysis of Chilkat Peninsula Muskeg, Alaska

Depth in decimeters	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Pinus contorta*	15	34	65	66	60	66	25	31
Picea sitchensis*	40	26	15	15	12	16	47	64
Tsuga heterophylla*	32	31	18	15	22	15	28	5
Tsuga mertensiana*	14	9	1	3	5	3	0	0
Unknown**	11	10	8	5	4	6	5	7
Polypod	3	4	—	3	3	3	84	350
Equisetum	—	—	—	—	—	—	—	3225
Lycopod	—	—	—	1	—	—	—	—
Cyperad	39	21	7	9	5	2	7	4
Lysitchitum	—	—	2	4	3	1	8	—
Salix	—	—	2	—	—	—	1	—
Alnus	55	68	12	27	38	35	1225	300
Betula	51	18	2	—	—	—	—	—
Ericad-Empetrad	6	1	9	9	3	8	10	1

*Percent of total count.
**Unknown conifers included in total count.

Horsetail (*Equisetum*) spores are exceedingly abundant at the bottom of the section (3225 at 0.7 meter) with numerous fern spores and alder grains (table 3). Birch (*Betula*) and sedge pollens are increasingly present in the upper peat.

DISCUSSION

Development of vegetation following the recession of Wisconsin ice in this portion of southeastern Alaska is essentially similar to the pattern recorded in muskegs from localities previously studied. Excursion Inlet section contains as much a record of postglacial forest succession and climate as has been found elsewhere in "panhandle" sections. Like other oldest muskegs, it does not seem to have been affected by differential uplift and eustatic sea level change. Although no geologic evidence for readjustment has been found in the literature concerning the site, the reason for this conclusion is the preponderance of pine pollen in the bottom sediments. The oldest muskeg in the Juneau area, 30 miles east, contains abundant pine at the bottom. This location is 750 feet above sea level. Muskegs successively nearer sea level disclose increasingly truncated profiles, and all lack a basal pine zone. Since marine fossils have been found as high as 500 feet in the area, the muskeg studied above this elevation is presumed to have been unaffected by marine transgression following ice retreat. The elevated position of Excursion Inlet muskeg site above a postglacial upper shoreline coupled with suitable conditions of climate and drainage has enabled pollen sedimentation to be recorded from the time of the first arboreal invaders.

Relatively drier and cooler climate has retarded the growth of muskeg in upper Lynn Canal. It was not until the wetter late-postglacial "little ice age" (Period IV) that muskeg development began. Prior to this, warmer and drier climate (Period III) precluded peat accumulation. Pollen stratigraphy in the Chilkat Peninsula muskeg would support this view. Absence of mountain hemlock and a low percentage of western hemlock at the base of the section with a large proportion of Sitka spruce imply lower amounts of moisture. The quantity of western hemlock in the Chilkat section is less than in any other obtained in southeastern Alaska. Its gradual rise from the bottom to the surface is concomitant with increased moisture. Lodgepole pine rise also favors this interpretation. Western hemlock invaded the spruce forest from the south when conditions became favorable. Rise of spruce at the top of the profile is a result of succession on recently deglaciated land.

Physiography must also be taken into consideration in order to explain the scarcity of muskeg along upper Lynn Canal. North of Berners Bay on the east side of the canal, rock walls bordering the fiord are too steep for muskeg formation. This terrain is typical for almost all of the region. On the west side of the canal there are suitable localities, although muskeg is not apparent north of St. James Bay. This side of Lynn Canal is in the rain shadow of the Chilkat Range.

Icy Point muskeg likewise began during Period IV, but its growth is only partially a consequence of increased moisture. Recent uplift is the most important factor responsible for the shallow accumulation. Mertie (1933), as

previously mentioned, has reported on the series of uplifted terraces in this region. Twenhofel (1952) also mentions Mertie's work. He concludes that there is no information to indicate the date of uplift. Pollen stratigraphy from the lowest terrace would imply that this surface had been uplifted in late-postglacial time. Young spruce forest growing on the terrace, shallowness of the peat in this wet climatic district, and beach sand underlying the peat, corroborate the pollen evidence for recent uplift.

Muskeg on the next higher terrace, 200 feet above sea level and 2000 feet in width (Mertie, 1933), was observed from the air to extend for miles parallel to the beach. It was originally planned that a section be obtained here as well as from the lower terrace. A comparison of peat sections and pollen profiles from the two might reveal the length of time between successive uplift of the terraces, if such has taken place. The time available, however, was insufficient to permit sampling the higher terrace. This approach to the problem of dating the uplift of the terraces may offer a simple means of solution in view of the existence of a postglacial chronology for the region.

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Department of Exploration and Field Research
American Geographical Society
New York, New York

REVIEWS

Record of the Rocks: The Geological Story of Eastern North America; by HORACE G. RICHARDS. Pp. xiii, 413; 294 figs. New York, 1953 (The Ronald Press Co., $6.00).—This book differs from the usual historical geology text in that the author intends to show the development of the Earth by a study of the Appalachian Mountains and the Atlantic Coastal Plain. This he does with remarkable consistency throughout, with only short sections being devoted to the rest of North America.

The first five chapters are a thorough summary of the bases and methods of historical geology including present-day land and sea movements and the origin and significance of fossils. The latter section is especially well written.

Two chapters present a classification of animals and plants. The inclusion of the trilobites in the Crustacea is to be criticized, but in other respects the organization is useful and up to date. Unfortunately, the mammals are not classified. The explanation for this is their scant record in eastern North America, but various mammal groups are referred to later in the text and their inclusion in this classification would be of value to students using the book.

A final introductory chapter covers the origin of the Earth. Several theories are summarized and excellently illustrated.

Geologic history is treated in the conventional way, period by period, but the emphasis is on Cretaceous to recent history. The Cretaceous rates the longest chapter in the book and each Cenozoic epoch is given individual attention. These chapters represent a valuable compilation of the literature on Coastal Plain geology to which have been added new paleogeographic maps that show shoreline changes almost age by age. The author suggests that an instructor can use this material as "an example of how more detailed geologic history can be worked out."

Chapters on earlier history contrast strongly with the later units. The Precambrian is summarily treated; no attempt is made to chronologize the Archeozoic-Proterozoic record or even to separate this from the events presumably connected with the formative period in Earth history. The Paleozoic is treated in more detail than the Precambrian but is written in a less attractive manner than the Mesozoic-Cenozoic history. Several statements and ideas are subject to criticism. The difficulties involved in explaining the sinking of a geosyncline do not excuse using the weight of the sediments for that purpose; further, the limestones and dolomites of the late Cambrian were probably not formed by fine material carried by sluggish streams as stated on page 117; and the Squantum "tillite" is not generally considered to be of Permian age as indicated on page 223. These and a few other similar examples which could be cited emphasize the lesser treatment given the Paleozoic. The Triassic and Jurassic chapters are better and lead naturally to the Cretaceous-Cenozoic chapters discussed previously in this review.

The introductory chapters as well as those on Mesozoic-Cenozoic history are interestingly and clearly written. It is unfortunate that the Precambrian and Paleozoic were not accorded equal treatment. Mechanically the book seems in good shape. A few figures are mislabeled and some erroneous figure

references were found in the text. The illustrations are good, but those of fossils would be greatly improved if there were some indication of scale.

The book contains an excellent summary of Atlantic Coastal Plain geology as well as new maps and interpretations which will make it a valuable general reference on that subject. Its usefulness as a textbook will be greatest where field trips on the Coastal Plain are feasible. WILLIAM A. OLIVER, JR.

A Thousand and One Questions on Crystallographic Problems; by P. TERPSTRA. P. 196; 183 figs., Groningen, 1952 (J. B. Wolters, 12.50 Dutch guilders).—A book without a table of contents, like an uncharted ocean, is hard to use in direct proportion to its size. Fortunately, the book here considered is not large, so that the difficulties of learning its contents can be easily overcome, especially with the aid of the index (about 180 entries with nearly 230 page references). The chapters have to do with the following subjects: 1, Miller indices (rhombohedral coordinates); 2, Geometrical crystallography; 3, Rhombic section; 4, Transformations; 5, Twins; 6, Gliding; 7, Lattices; 8, Crystal drawing; 9, Crystal optics; 10, Laue patterns, space groups, and Weissenberg patterns; 11, Structure-factor calculations.

Although few American students will be able to go through all the exercises in this book without considerable strain, I can sincerely hope that many will use it, for in using it they will develop a better understanding of important fields of crystallography that might otherwise remain unfamiliar. Would that we had had such a book long ago! HORACE WINCHELL

Fouriersynthese von Kristallen, und ihre Anwendung in der Chemie; by WERNER NOWACKI. P. 237; 120 figs. Basel, 1952 (Verlag Birkhäuser, 34.30 Swiss francs clothbound, 30.15 in paper.—Many papers had to be summarized in preparing this valuable and long-needed textbook: references to the literature through 1948 are numerous; some extend into 1949. The student may find a few instances in which he must refer to the original papers to obtain full details for a proper understanding of the subject, but the book as a whole seems thorough and well written.

The organization is complex for so short a treatise. Part *A* is theoretical, *B* is practical; Chapter 1 deals with the basic Fourier syntheses. From the three-dimensional Fourier series with coefficients $F(hkl)$, special sections and projections are derived; full examples of their uses are given. The chapter concludes with discussions of accuracy, methods of refinement of parameters, and methods of determination of the phase angle. Chapter 2 covers the several types of series with Fourier coefficients $|F|^2$, according to Patterson, Harker, and Buerger. A separate, paperbound table of Buerger's 120 diffraction groups is provided in a pocket in the back cover of the book for use with this chapter and elsewhere. Chapter 3 is coextensive with Part *B;* it describes most of the special calculating aids such as Beevers-Lipson strips and several kinds of mechanical, optical, and electronic computers.

This work should find its greatest popularity with students at a moderately advanced level but it is important to all scientists interested in the application of crystallographic Fourier series in their respective fields.

HORACE WINCHELL

Geology and Mineral Deposits of Pre-Cambrian Rocks of the Van Horn Area, Texas; by PHILIP B. KING and PETER T. FLAWN. P. 218; 24 figs., 36 pls. University of Texas, Bureau of Economic Geology, Publication 5301. Austin, 1953 (The University of Texas, $5.75 in cloth, 5.00 in paper).—The volume under review describes most of the areas of Precambrian rocks in West Texas, omitting only the areas in the Hueco and Franklin Mountains near El Paso. The description of the southern, more metamorphosed areas by Flawn emphasizes the petrology; meta-arkose, schist (garnet grade), and amphibolite to the south have been somewhat retrograded toward the north under strong cataclastic deformation. The description of the northern area by King emphasizes the structural geology; rocks like those farther south though even lower in metamorphic grade have been thrust northward over a quite different sequence of rocks along a major low-angle fault; the second sequence is complexly deformed near the major fault but much less so farther north. The rocks thus give us a glimpse of a craton-orogen boundary at an unspecified moment in the Precambrian.

The descriptive matter is supported by outstanding illustrations. There are nine fine collotype plates of outcrops or landscapes and seven of photomicrographs. One of the revealing sketch panoramas that have become a King trademark is included, as well as a joint map like the one in King's Guadelupe Mtns. Professional Paper. Nothing has been spared to make this publication handsome and worthy of the great state of Texas.

JOHN RODGERS

Triassic Life of the Connecticut Valley [revised]; by RICHARD SWANN LULL. P. 336; 168 figs., 12 plates, 3 maps. Hartford, 1953 (State Geological and Natural History Survey Bulletin 81).—Bones were discovered in the Triassic beds of the Connecticut Valley in 1818. The presence of footprints in those strata was known even earlier, and their technical description was begun by Hitchcock in 1836. Hitchcock's "Ichnology of New England" (1858) retains a place not only among the curiosa but also among the classics of American paleontology. Beside it has long stood Lull's "Triassic Life of the Connecticut Valley" (1915). In that work the footprints were redescribed in modern terms, along with the scanty tetrapod bones, most of them found after Hitchcock. Lull's monograph also considered the whole picture of late Triassic life in New England and was a pioneering study of what is now called paleoecology. It, too, was a landmark in the history of American paleontology and has become a classic. The appearance of a revised edition will be welcomed by all of Professor Lull's colleagues.

No really important new discoveries in this immediate field have been made since 1915, so that revision has been more modernization than extension. Much of the text is unchanged from the first edition. Discussion of environmental conditions has been brought into line with Krynine's study of the sediments (1950). Classification of the bones and footprints has not been changed in essence, but the nomenclature of genera and higher groups is somewhat modified, mainly after von Huene and Romer. Although evidently valid, some of these changes are a little baffling, for instance when an earlier

generic reference is written as if it were a subgenus, e.g., "*Clepsysaurus (Rutiodon)*," or a changed generic name, e.g., *Stegomosuchus*, is introduced with no mention of the author, date, or reason for the change.

The greater part of the study is of course still devoted to the footprints. Illustrations of them have been redrawn and have been improved by omission of the inferred foot bones. An interesting new feature is illustration of eleven models of the otherwise unknown track-makers. It is no detraction from this fascinating accomplishment to correct a possible implication that restorations from footprints are novel. Similar attempts date back to 1855, at least, and in 1925 Soergel published a plastic model made in just the same way as Lull's. Lull contributes to methodology in another section new in this edition. Statistics of dimensions are graphed, and D'Arcy Thompson's method of deformed coordinates is applied to footprints.

It is good to have the "Triassic Life" back in print, and especially to have it reworked by the ever-active mind and hands of the revered teacher who first wrote it nearly forty years ago.

G. G. SIMPSON

Problems of Life; by LUDWIG VON BERTALANFFY. P. xi, 216. New York and London, 1952 (John Wiley & Sons, Inc., and Watts & Co., $4.00).—To anyone familiar with von Bertalanffy's previous writings, *Problems of Life* will reveal no great novelties or surprises. It will, however, provide for such readers a summary of twenty years of consideration and work in the most difficult and, in some ways, most important area of biological thought. Readers new to Bertalanffy's ideas, and these are probably most numerous among non-biologists, can extract from the book a conception of the methodological problems facing workers in the field of life sciences, as well as of the kind of linguistic confusion to which writers in this field (Bertalanffy not excluded) have fallen prey.

Biologists have for a very long time wrestled with the problem of explanation. The author distinguishes three schools of explanation; vitalist, mechanist, and holist, the last named being, in his opinion, the only reasonable one. One would have thought the doctrine of vitalism, with its assumption of an *elan vital* driving systems to a predetermined and perfect end, to be quite forgotten in biology. The author of *Problems of Life*, however, seems not to be satisfied that the ghost is laid and spends considerable time in pointing up the difficulties of the vitalist viewpoint. The main effort of the book, however, is devoted to the inadequacy of the mechanistic approach in explaining biological phenomena. The principle that the observable facts of biology can be reduced to the realm of physico-chemical explanation is refuted, while in its place a system of laws specially valid for living systems is proposed.

Like those in other sciences, biological explanations are, in the main, reductive. That is, an observed phenomenon is "explained" by logical deduction from a set of general laws together with a set of special conditions which insure that the phenomenon in question does, in fact, fall under these laws.

Vitalistic, mechanistic and holistic explanations are all of this form, and in distinguishing among them some criterion other than their "truth" must

be established. Bertalanffy's argument that vitalism must be rejected because the vital force which it presupposes is not susceptible to direct observation, cannot be considered valid, for by this criterion such highly useful terms as "force," "energy," "gene," and "light wave" must also be rejected. Vitalism has been discarded because it is an unfruitful concept. By its terms biology is reduced to a purely observational science in which all questions, "Why?" are answered, "Because there is an inner will to perfection."

On this same ground the author's holistic concept also is to be criticized. It is undoubtedly true that there are laws which are peculiar to biologically complex systems in the sense that they are formulated in the language of biology. To deny that these laws can be reduced to those of physics and chemistry is an untested dogma. Bertalanffy's "proofs" of the inapplicability of classical thermodynamics to biological systems are in large part alogical or based upon overly restrictive definitions of mechanistic principles. His assertion, for example, that equifinality is a property *only* of biological systems is nullified by the fact that this is a property of all reversible chemical reactions. Organismic theories, then, share with vitalism the fault of not asking "Why?" often enough. An holistic system when carried to extremes is sterile for its laws are regarded as the irreducible basis of explanation.

The attack upon biological systems at an integrated level can be an extremely fruitful method when stripped of its irreducibility dogma. Biologists have discovered only a few of the general laws governing living systems. There is at present an overemphasis on the physico-chemical explanation of life, when in fact the general laws which these physico-chemical events are to explain are only poorly known.

Bertalanffy's thesis, then, is highly relevant to the present status of the life sciences, but the ultimate fruitfulness of the holistic approach must be recognized as dependent upon our ability to reduce holistic laws to more basic disciplines.

RICHARD LEWONTIN

Biology and Language; by J. H. Woodger. The Tarner Lectures 1949-50. P. xiii, 364. New York and Cambridge, 1952 (Cambridge University Press, $8.00).—So seldom has a really lucid and trained mind devoted itself to methodological problems in biology that the very words "methodology" and "linguistics" bring forth only an indulgent smile from biologists. To such sceptics *Biology and Language* will be a revelation. Professor Woodger has clearly shown that a rigorous treatment of biological concepts can be fruitful not only in indicating the direction which future research ought to take but in resolving the past confusions over which biologists have labored *ad nauseam.*

This book is not an easy one to read, especially for those untrained in the methods of set theoretical logic. It has been the unfortunate experience of serious students of methodology that research workers are unwilling to devote the time and energy required to achieve an adequate facility with and understanding of symbolic logic. Although partly due to a preoccupation with other aspects of their science, it is also partly due, one suspects, to a fear that pet

concepts may prove untenable or at least not susceptible to test or proof. It is to be hoped that this indifference will be broken down by the author's very clear and ingenious presentation.

The first section of the book is devoted to a simple exposition of the technical jargon and methods of the logician. Having laid the groundwork, the author proceeds to an extremely interesting analysis of classical genetics, beginning with observation statements. Perhaps the most important portion of this discussion is devoted to the construction of a *combined algebra* which allows the usual operations on sets to be combined with numerical operations so that quantitative measurements can be dealt with in a rigorous way. Woodger's combined algebra bears close resemblance to set theoretical probability theory and its concept of the random variable, both in the kinds of problems the two systems are capable of handling and in their formal structure. The fact that a system of such evident power has been evolved quite independently by the author testifies to his unusual insight and ingenuity.

It may be that genetics can be more profitably treated from an axiomatic approach rather than that used by Woodger. Such an approach could make use of the already extensive apparatus of probability theory and at the same time circumvent one of the major difficulties in the use of observation statements. This difficulty concerns the inference of general laws about the expected results of genetic crosses from data subject to sampling error. Thus, if one were to observe 93 offspring of one type and 29 of another, this would be taken as evidence of the well known 3:1 ratio. It is then necessary to ask how aberrant can the observed proportion be before such a ratio is no longer inferred. Beginning with observation statements alone, there seems no satisfactory answer, while an axiomatic, probabilistic treatment of genetics encompasses just such problems.

This discussion typifies, in a way, the only serious criticism of Woodger's discussion of genetics. There is a tendency for oversimplification, which may stem from a lack of contact with recent genetical research. To be truly useful to the geneticist, the formal logic of his field must allow of the treatment of data subject to sampling error, of the continuous rather than discrete nature of his experimental results despite an apparent discreteness of the underlying mechanism, and in general of the probabilistic nature of the universe with which he deals. It is, however, only fair to point out that the discussion in *Biology and Language* is meant primarily as an example of what linguistic analysis can do, rather than as an intensive research into genetical methodology.

The last portion of the book is concerned with neurology and psychology. It is here, I think, that Professor Woodger is less convincing. Problems of perception and psyche have been a primary concern of metaphysics for a very long time, yet we seem no closer to their solution. The author points out quite rightly that linguistic analysis can do away with some of the confused thinking which has been rampant in this field, but he fails, it seems, to demonstrate convincingly its constructive role. Nevertheless, as he points out in conclusion, patience above all else is required.

It may be that the revolution which methodology has invoked in the physical sciences will encourage more and more biologists to consider seriously the value of a formal re-examination of their knowledge and concepts. Works like *Biology and Language* will certainly be invaluable in initiating this re-examination and perhaps in invoking an equally vigorous revolution in biology.

RICHARD LEWONTIN

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